
The effects of stocking rate and ewe prolificacy potential on the efficiency of lamb production and grass utilisation in pasture based systems

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Declaration

I hereby declare that the work reported herein is my own and that this thesis has not previously been submitted as an exercise for a degree at the National University of Ireland, or any other University.

Elizabeth Earle, January 2017

Dedication

I would like to dedicate this thesis to my family who have supported my passion for sheep farming and all things agriculture from a young age and for their constant love and encouragement throughout my studies.

‘The best way to predict the future is to create it’

Abraham Lincoln

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Glossary of Terms

283		
284	ADF	Acid detergent fibre
285	ADG	Average daily gain
286	ARFC	Agriculture and Food Research Council
287	BCS	Body condition score
288	cm	Centimetre
289	CP	Crude protein
290	CSH	Compressed sward height
291	DAFM	Department of Agriculture, Food and Marine
292	g	gram
293	Ha	Hectare
294	HP	High prolificacy
295	HSR	Higher stocking rate
296	Kg	Kilogram
297	LSR	Low stocking rate
298	ME	Metabolisable energy
299	MP	Medium prolificacy
300	MSR	Medium stocking rate
301	NDF	Neutral detergent fibre
302	OM	Organic matter
303	OMD	Organic matter digestibility
304	PP	Prolificacy potential
305	SEM	Standard error of the mean
306	SR	Stocking rate

307	UFL	Unite fourrage laite
308	DM	Dry matter
309	DMD	Dry matter digestibility
310	PGSH	Post-grazing sward height
311	%	Percentage
312	°C	Degrees Celsius

Abstract

Ewe prolificacy potential (PP; predicted number of lambs born per ewe per year) and stocking rate (SR; ewe per ha) are two primary drivers of output in temperate grass-based lamb production systems. The aim of this thesis was to investigate and quantify the effect of ewe PP, SR, and their interaction on animal performance, pasture production and utilisation and the efficiency of lamb production in a grass-based production system. A 2 x 3 factorial design study, consisting of two ewe PP ((medium prolificacy potential (Suffolk X ewes; 1.5 lambs reared per ewe) and high prolificacy potential (Belclare X ewes; 1.7 lambs reared per ewe)) and three SR: low (10 ewes per ha), medium (12 ewes per ha), and high (14 ewes per ha) was conducted. Each treatment was managed in a rotational grazing system. Measurements taken included; ewe body weight, ewe body condition score (BCS), number of lambs born and weaned per ewe and per hectare, lamb growth rate, days to slaughter, lamb carcass traits and output, ewe production efficiency (kg lamb live weight weaned: kg ewe live weight mated), herbage dry matter (DM; kg) production and utilisation, sward quality and morphology, and DM and energy (Unite fourrage laite per kg DM; UFL) consumption. High PP ewes produced more lambs both per ewe and per hectare, with HP lambs achieving a higher average daily gain (ADG) on a per hectare basis and yielded a higher lamb carcass output per hectare compared to MP ewes. The total quantity of DM and UFL consumed per ewe and lamb unit for the full production year did not differ by ewe PP. The HP system required a lower quantity of DM and UFL to produce a kilogram of lamb carcass. The use of higher stocking rates demonstrated the potential to increase lamb carcass output per hectare in a grass-based lamb production, with the LSR and MSR systems achieving similar levels of performance for pre-weaning lamb ADG and days to slaughter. Increasing stocking rate increased herbage production, utilisation and sward quality and leaf content. Limitations to increasing stocking rate above 12 ewes per hectare in a grass-based lamb production system due to reductions in individual animal performance and increases in DM and UFL consumption per ewe and lamb unit and per kilogram of lamb carcass produced at the HSR were recorded. The findings from this thesis demonstrate the potential to increase lamb output and the efficiency of lamb production from a temperate grass-based lamb production system through targeted increases in ewe PP and SR levels.

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1. Chapter One
General Introduction

1.1 Thesis background

Grazing systems occupy approximately 26% of the earth's terrestrial surface (Steinfeld et al., 2006) with intensive dairy, beef and sheep production systems predominantly operated in temperate climatic regions (Dillon et al., 2005). Such systems are a vital indirect source of nutritional energy, protein, and micronutrients for the world's growing population (Boland et al., 2013; Erb et al., 2012), which is predicted to increase by 30% to over 9 billion people by 2050 (United Nation, 2015). To meet the increased demands in global nutrition, annual food production globally will need to increase from 8.4 billion to 13.5 billion tonnes (FAO, 2014). Achieving this increase in food production is challenging due to the depletion of natural resources and grassland areas and will have to be produced from the current constrained land base area (Smith, 2013). This intensifies the requirement for the development of more efficient and sustainable agricultural livestock production systems through the modification of current practices and improvements of efficiency in the use of resources (FAO, 2014; O'Brien et al., 2016).

Sheep produce four main products; meat, wool, milk, and skins, with sheep breeds in temperate grazing regions predominantly used to produce meat (Morris, 2009). Despite, the lower consumption levels of sheep meat at 1.7 kg per capita globally relative to beef, pork, and poultry, the global consumption of sheep meat is forecast to increase by approximately 20% by 2025 (OECD, 2016), with the global sheep population estimated to increase from 1.7 billion to 2.7 billion by 2050 (Thornton, 2010). Currently, the European Union accounts for 12% of global sheep meat consumption (Colby, 2015) and is only 88% self-sufficient in sheep meat (EC, 2015) relying on imports from New Zealand and Australia to fulfil market demands (Colby, 2015). In Ireland, relative to the total quantity of sheep meat produced annually, the domestic consumption of sheep meat is low, resulting in nearly 80% of sheep meat produced being exported in 2015 (Bord Bia, 2016).

Grass-based livestock production systems in Ireland have the potential to grow between 11 to 15 tonnes of grass dry matter (DM; kg) per hectare annually, and are characterised by a long temperate grass growing season (>240 days; Brereton, (1995)). However, total annual grass DM production varies considerably across farms, depending on location, farm type, season, and grazing management decisions applied (O'Donovan et al., 2016; Shalloo et al., 2010). Herbage utilisation levels at farm level can be increased through the measuring and budgeting

of pastures and the use rotational grazing systems. The winter housing and coordination of lambing date of the breeding flock in Ireland (Bohan et al., 2016; Keady et al., 2009), allows Irish sheep producers to align flock requirements with the seasonal pattern of herbage growth (Brereton, 1995). Grass, either grazed or conserved, has the potential to supply up to 95% of the energy requirements of sheep (Davies and Penning, 1996), although many producers cite increasing annual herbage production and utilization in lamb production systems to be a challenge at farm level (Creighton, 2015). Grass utilisation is one of the most important factors influencing productivity and profitability of grass-based livestock systems (Macdonald et al., 2008). The lower associated cost of production of grazed grass relative to alternative feed sources (Finneran et al., 2010) provides an opportunity for producers in temperate grazing regions to produce lamb from a primarily grass-based diet in a cost-effective manner (Clark et al., 2010; Dillon, 1995; Keady et al., 2009).

Ewe prolificacy potential (PP; predicted number of lambs born per ewe per year; Davis et al., 2006) and stocking rate (SR; ewes per ha; Allen et al., 2011) have been identified as two of the most influential factors affecting lamb production per ewe and per hectare (Dawson and Carson, 2002; Keady et al., 2009; NFS, 2013). Such factors will play a pivotal role in achieving the required increases in global lamb production (Thornton, 2010). In Ireland, the average lowland flock and farm size is relatively small at 107 ewes (DAFM, 2015) and 32.7 hectares (CSO, Census of Agriculture 2011) in comparison with sheep production systems in other temperate grazing regions (AHDB, 2015). This intensifies the need for Irish producers to increase the efficiency of their production systems in order to remain profitable (Connolly, 2000; Keady et al., 2009).

The Food Wise 2025 policy document highlighted the importance of the use of the latest scientific technologies, sheep genetics and breeding in the future development of Irish lamb production systems (DAFM, 2015). Previous research has shown increases in SR impact positively on herbage production, utilisation, and quality and increases in animal production per hectare in temperate grass-based ruminant production systems (Macdonald et al., 2008; McCarty et al., 2016). However, such increases in production are often achieved at the expense of individual animal performance (Macdonald et al., 2008) which is primarily attributed to reductions in feed availability per animal as SR increases (Baudracco et al., 2010). At present, there is a paucity of information on the effects of ewe PP, SR, and their interaction on animal and pasture performance in a temperate grass-based lamb production

system. Gaining an understanding of the effects of such factors is paramount to the development and optimisation of future temperate grass-based lamb production systems.

1.2 Thesis Outline

The objective of this thesis is to investigate and establish an understanding of the effects of ewe PP, SR, and their interaction on lamb production from a temperate grass-based system. The hypothesis of this thesis is increasing ewe PP and SR will increase the productivity of grass-based lamb production systems and the efficiency of lamb carcass production. This thesis provides scientific knowledge on animal and pasture performance in a mid-season, temperate, grass-based lamb production system, with a focus on evaluating the effects of ewe PP, SR, and their interaction on both primi- and multiparous ewe performance, lamb growth, carcass traits, herbage production, utilisation, quality, and sward morphology. In addition, such effects on measures of system efficiency and the conversion of herbage DM to carcass were also investigated.

Chapter Two provides a detailed review of the literature relating to temperate grass-based lamb production systems, ewe PP, SR, and factors influencing animal and pasture production in temperate grazing systems.

Chapter Three evaluates the effect of ewe PP, SR and their interaction on primiparous flock performance and provides a detailed description of primiparous ewe and lamb performance throughout the production year in a temperate grass-based lamb production system differing in ewe PP and SR.

Chapter Four assesses the effect of ewe PP, SR and their interaction on multiparous flock performance in a mid-season temperate grass-based lamb production system over three production years and examined the effects of ewe PP, SR, and their interaction on key performance indicators such as ewe body weight, body condition score, lamb birth weight, mortality, average daily gain, weaning rate and carcass traits.

Chapter Five quantifies the impact of ewe PP, SR and their interaction on herbage production, utilisation, quality, and sward morphology in a temperate grass-based lamb system.

Chapter Six Measures and evaluates the effect of ewe PP, SR, and their interaction on the efficiency of lamb production in a temperate grass-based system.

Chapter Seven summarises the main results and provides a general discussion of the research findings in this thesis.

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2. Chapter Two

Literature Review

2.1 Introduction

At present, there are 35,254 sheep flocks, comprising of 2.5 million breeding ewes in the Republic of Ireland (DAFM, 2016). The Irish sheep sector contributed a total of €285 million to the gross agricultural output value of the Irish economy in 2014 (DAFM, 2015). Ewe prolificacy potential (PP; predicted no. of lambs born per ewe per year; Davis et al., 2006) and stocking rate (SR; ewes per ha; Allen et al., 2011) have been identified as two key determinants of flock productivity (Davis et al., 1998; Keady et al., 2009). At present, lamb carcass output per hectare (191 kg carcass per ha) in Ireland is limited by low SR of 7.3 ewes per hectare and weaning rates of 1.3 lambs per ewe (Teagasc, 2016a). Performance levels of 9 ewes per hectare and 1.4 lambs weaned per ewe are set as achievable industry performance targets for 2025 (Teagasc Roadmap, 2016).

Improving herbage production and utilization while maintaining optimum animal performance and subsequent lamb output (kg carcass per ha) from a grass-based diet (Davies and Penning, 1996) is a major challenge for lamb producers. The coordination of lambing date and flock feed demands to the seasonal pattern of pasture growth (Brereton, 1992), provides the opportunity to make optimal use of grazed grass and to enhance the productivity and profitability of lamb production systems (Bohan et al., 2016; O'Donovan et al., 2011). This literature review focuses on the influence of PP and SR on animal and pasture performance in a grass-based lamb production system.

2.2 Herbage production

2.2.1 Grassland production in Ireland

There is approximately 4.6 million hectares of grassland in Ireland, with permanent and rough grazing pastures accounting for 91% of total utilised agricultural area in Ireland (Drennan et al., 2005, O'Mara, 2008). The majority of this area is set out in long term permanent pasture, with a low proportion of approximately 1.5 to 2% of agricultural land reseeded annually with perennial ryegrass (*Lolium perenne*) the dominant species and smaller quantities of white clover (*Trifolium repens*) used (Humphreys and Casey, 2002; Shalloo et al., 2011). Soil type in Ireland, has a major influence on herbage production, with 62% of the total agricultural area in Ireland consisting of dry lowland mineral soils and a further 20% defined as moderately wet mineral soils and 17% wet impermeable mineral soils (Coulter et al., 1996).

Dry mineral soils are well suited for intensive grass production and are located in the south, midlands and east, with poorer quality soils located in the west and north, with recent work by Egan et al. (2017) demonstrating soil type to have a greater effect on herbage growth compared to geographical location in Ireland. The grass growth curve and total herbage production ((kg dry matter (DM) per ha per year)) for a given region globally varies considerably and is largely influenced by local climatic conditions, with rainfall, temperature and radiation considered the key factors affecting the annual pattern of herbage production, along with grazing management practices applied (Drennan et al., 2005; Hurtado-Uria et al., 2013).

2.2.2 Climate

Ireland is ideally suited to herbage production due to its temperate climate, its location between 51°N and 55°N latitude and the influence of the prevailing westerly winds and its close proximity to the Atlantic Ocean and the Gulf Stream. Average rainfall in Ireland ranges from 750 mm in lowland areas of the east/northeast to over 1200 mm in the west and south west (Keane and Sheridan, 2004; Met Éireann, 2017). February to July is considered to be a drier period compared to August to January, which can be relatively wet (Drennan et al., 2005). Soil moisture deficits in Ireland, generally have very little impact on herbage production, with minor losses of herbage production potentially occurring along a narrow coastal area in the east and south east (Brereton & Keane, 1982; O'Leary et al., 2016). Soil temperature plays a crucial role in the onset and duration of the grass growing season, with the grass growing season beginning when soil temperatures are above 5°C in temperate regions in the spring (Hopkins, 2000) and concluding in autumn when temperatures drop below 8°C (Brereton et al., 1985; Broad and Hough, 1993).

2.2.3 Seasonality of grass growth

In temperate grazing regions such as Ireland, United Kingdom, New Zealand and central Australia, the seasonal pattern of pasture growth is typically characterized by a long grass growing season. Herbage production in these regions has a seasonal pattern of growth (spring to late autumn), which is regulated by temperature. In Ireland, as temperature rises in the spring (typically March; Fig. 2.1) grass growth increases rapidly, with a peak in production of approximately 90 kg DM per ha per day in late spring/early summer (May) and a secondary

peak of grass growth of approximately 65 kg of DM per ha per day in August, followed by a decline in growth over the late autumn/winter period (Brereton, 1992).

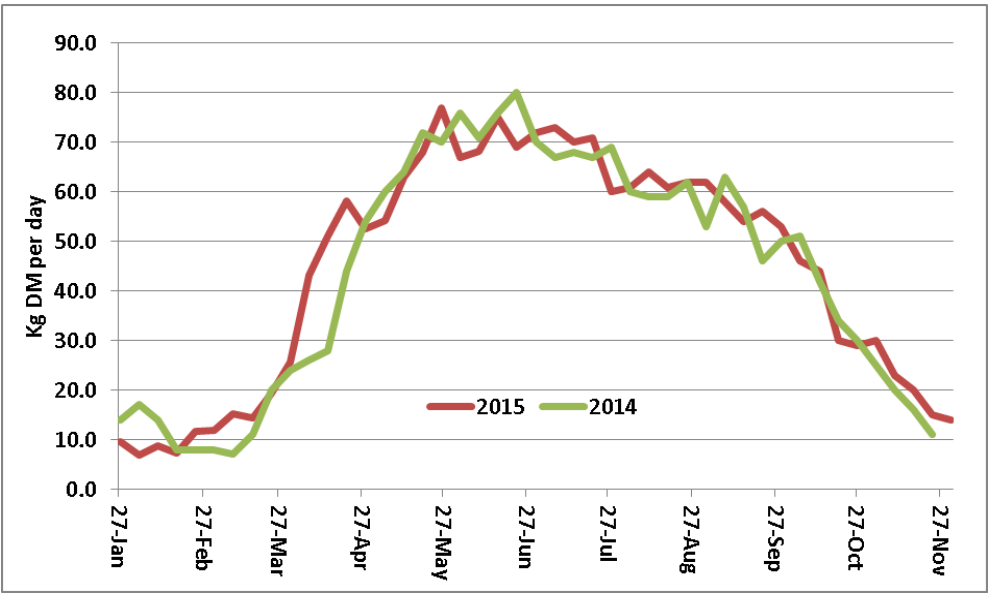


Figure 2.1 Grass growth curve recorded on Irish farms in 2014 and 2015 (kg DM per ha per day; O’Leary et al., 2016)

The length of the grass growing season has been defined as ‘the period in which the temperature of the air or that of the soil consistently exceeds the minimum value associated with the growth of a particular crop’ (Keane, 1992). The threshold temperature required for grass growth is considered 5°C, with maximum grass growth rates occurring between 18 and 24°C (Frame, 1992). Herbage DM production levels in Ireland varies annually depending on the length of the grass growing season, with grass growth season lengths varying from 330 days in the southwest to 240 days in the northeast. O’Leary et al. (2016) reported annual herbage production levels from 10.5 to 12.4 tonnes DM per ha to be achievable on dry stock farms in Ireland, with soil fertility and grazing management (rotational grazing and paddock size) having a greater impact on herbage production relative to location (Fig 2.2).

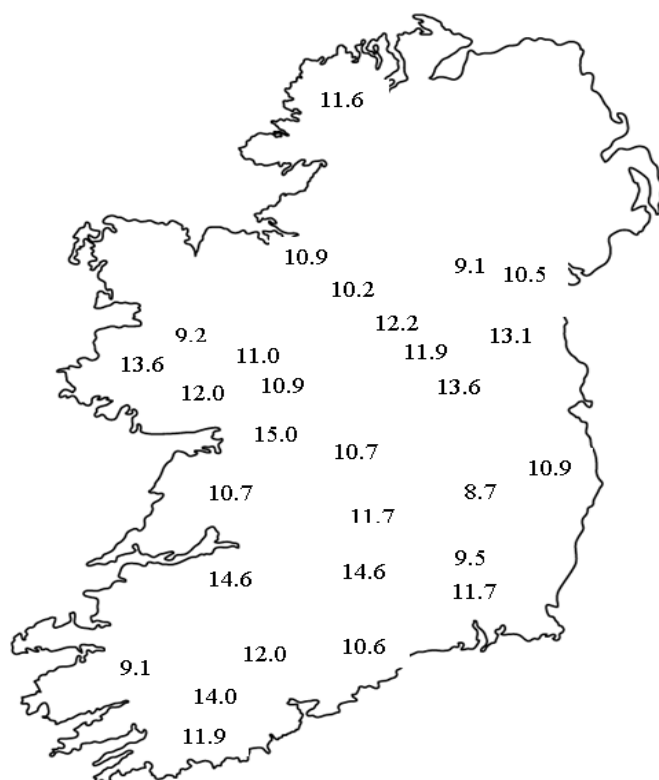


Figure 2.2 Annual herbage production in Ireland (tn dry matter per ha; O’Leary et al., 2016)

Despite Ireland having a similar pattern of grass growth to that of the north island of New Zealand, and Australia, the annual herbage production between these regions varies considerably as shown in Table 2.1. This demonstrates the significant influence that local climatic conditions, particularly temperature and rainfall can have on herbage production.

Table 2.1 Average temperature, rainfall and herbage production for Ireland, North Island New Zealand and Australia.

	Ireland	New Zealand (North Island)	Australia
Temperature °C	9.8	14.2	13.2
Rainfall (mm/year)	1024	1117	1029
Herbage production (kg DM per ha per year)	12 726	19 035	10 870

Adapted from Dillon et al. (2005)

2.2.4 Perennial ryegrass

Perennial ryegrass (*Lolium perenne*) is considered one of the most important forage grass species used to supply nutrients for grazing animals in temperate regions around the world, especially Western Europe, New Zealand and Australia (Rattray, 2007, Wilkins and Humphreys, 2003). It is a low cost feed source in livestock production systems in Ireland (Finneran, et al., 2010; Teagasc, 2016b), with a relative cost ratio of grazed grass to grass silage and concentrate of 1: 1.8: 2.4, respectively. Its perennial lifecycle means it can survive in grazing pastures for many decades under suitable conditions and it has many positive attributes including rapid establishment, increased herbage yield, high nutritive value and high response to nitrogen (Frame, 1992) when high levels of nitrogen are applied..

2.2.5 Grazing management practices

The main objective of grassland management for sheep systems is to supply high quality digestible pastures to the grazing ewe and her lambs (Keady and McNamara, 2012). In lamb production, set stocking/continuous grazing systems are commonly operated (O'Mara, 2008) with sheep grazing the same grassland area throughout the grazing season. O'Mara, (2008) also reported rotational grazing to be commonly practiced in dairy and beef production systems. This involves dividing the grassland area into a number of paddocks, which are then grazed, fertilised and rested in turn and can allow for greater levels of herbage utilisation to be achieved (Webby and Bywater, 2007). Rotational grazing systems offer greater flexibility in grassland management (O'Mara, 2008), by providing increased control over sward structure, grazing severity, regrowth periods and overall pasture supply. Under both continuous and rotational grazing systems high lamb growth rates can be achievable (Grennan and O'Riordan, 1996), provided lambs graze to an optimum posting-grazing sward height such as those illustrated in Table 2.2 (Keady, 2010).

Table 2.2 Recommended target post-grazing sward heights (cm) for optimum lamb performance

Month	March	April	May	June	July/August	September
Continuous	5	5-6	6	6 - 7	7 - 8	8
Rotational	3.5 - 4	3.5 - 4	4.5 -5	5.5 - 6	6	6

(Sourced Keady, 2010)

2.3 Stocking rate

Stocking rate is defined as the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time (ewes per ha; Allen et al., 2011) and has a significant effect on output per unit of area of land (McMeekan, 1956). Stocking rate influences animal performance both at an individual and a per hectare basis (Macdonald et al., 2008; McCarthy et al., 2012a), and effects herbage production, utilisation, and quality in grass-based ruminant production systems (McCarthy et al., 2012b).

2.3.1 Effect of stocking rate on sward production

2.3.1.1 Herbage production and utilisation

The net annual herbage production (kg DM per ha) of a grazing system will determine the total level of herbage available for grazing animals and is a decisive factor in determining the amount of animal/carcass output that can be produced from grazed herbage in grass-based production systems (Keady et al., 2009; Macdonald et al., 2001). Ultimately SR is decided by the amount of herbage that is produced within a grazing system (Baudracco et al., 2010). Measurement of sward herbage mass (HM; kg dry matter per ha) is a useful technology in estimating the annual herbage production and can greatly assist in determining the appropriate SR for a grazing system. Such measurements include visual assessments of sward HM, cut and weigh, the rising plate meter, and sward stick (O'Donovan et al., 2002) all of which can be used to estimate sward HM.

Many detailed grazing studies of the effects of SR in temperate grass-based dairy cow (Macdonald et al., 2008; McCarthy et al., 2012b; McFeely and McCarthy, 1979) and sheep production systems have reported inconsistent effects of SR on herbage production and utilisation (Keady et al., 2009). As SR is a pivotal factor influencing herbage utilisation in grazing systems, achieving a balance between herbage production and the feed requirements of the grazing flock is vital in maximising both herbage utilisation and sward productivity.

The SR applied to a grazing area throughout the grazing season can have variable effects on herbage production and utilisation (Glindemann et al., 2009; MacDonald et al., 2008; McCarthy et al., 2012b). McCarthy et al. (2016) reported herbage production to increase from 14,479 to 15,410 kg DM per ha per year when SR increased from 2.51 livestock units (LU)

per ha to 3.28 LU per ha which is the equivalent of 12.5 ewes per hectare and 16 ewes per hectare, respectively. McCarthy et al. (2016) also reported a linear effect of SR on net herbage production of 1,664 kg DM per ha per year for each 1.0 LU increase in SR. Additionally as SR increased in a dairy cow grazing system pre-grazing HM increased and post-grazing HM decreased supporting increased levels of herbage utilisation per hectare, despite lower herbage consumption per cow (MacDonald et al., (2008). However, McCarthy et al. (2012b) observed no significant effect of SR on total herbage utilisation (mean=11,700 kg DM per ha) within a temperate grass-based dairy cow system.

Conversely, King and Stockdale, (1980) and McFeely and McCarthy, (1979) observed annual herbage production to decrease as SR increased as a result of increased grazing severity and reduced sward regrowth. The higher SR levels achieved greater herbage utilisation at each grazing. Therefore SR had a greater grazing efficiency (herbage utilized as a proportion of the pre-grazing herbage mass) relative to the medium and low SR levels. Total herbage utilized as grazed grass increased as SR increased.

2.3.1.2 Grazing severity and sward morphology

The structure of the grazing sward changes throughout the grazing season, as the grass plant goes through both vegetative and reproductive stages of development. This can greatly influence herbage production, utilisation and subsequent animal performance. The severity with which swards are grazed can have both desired and undesired effects on sward structure (Michell and Fulkerson, 1987; Lee et al., 2008). Increases in SR are typically associated with increased grazing intensity and reduced post-grazing heights/masses (Hoden et al., 1991; Kennedy et al., 2006), as a result of the greater number of animals competing for available herbage in the same grazing area.

Tuñón et al. (2013) reported the proportion of leaf material to increase from 0.56 to 0.67 and stem proportion to decrease from 0.30 to 0.21 as post-grazing sward height were decreased from 4.5/5 cm to 3.5/4.0 cm. Similarly Ganche et al. (2013) observed the proportion of leaf in the grazing sward to increase as grazing severity increased. Research by Lee et al. (2007) observed the proportion of stem material to decrease and the proportion of leaf material in the sward to increase as grazing severity increased. The opposite effects are observed with lax or infrequent grazing of swards, with low SR grazing systems often associated with higher proportions of senescence material in grazing swards (Hoogendoorn et al., 1992; Lee et al.,

2008). This has been shown to result in less digestible material present in grazing swards and is likely to reduce herbage intake and subsequent animal performance (Holmes et al., 1983; Stakelum and Dillon, 2007).

In addition, Spring grazing management also plays a vital role in conditioning the swards for the main grazing season, with lower post-grazing sward heights/residuals in springtime found to increase the proportion of leaf material in the swards (Holmes et al., 1992) and improved herbage quality in subsequent rotations (Baker and Leaver, 1986; Kennedy et al., 2006; Korte et al., 1984).

2.3.1.3 Herbage nutritive value

The nutritive value of grazing pastures is one of the most influential factors on herbage utilisation and animal performance in temperate grass-based production systems (McCarthy et al., 2012b). Improvements in sward quality and digestibility are positively associated with increased animal performance. Many factors influence herbage nutritive value including: pasture species, stage of plant growth, grassland management (i.e. pre- and post-grazing HM), the application of organic and inorganic fertilisers, and environmental conditions.

Increases in SR and grazing severity are generally associated with improvements in sward nutritive value (Lee et al., 2008; Tuñón et al., 2013). Macdonald et al. (2008) reported a significant increase in herbage organic matter digestibility (OMD) and energy content as SR and grazing severity increased but a quadratic decline in fibre components: neutral detergent fibre (NDF) and acid detergent fibre (ADF) in grazing swards. McCarthy et al. (2012) observed no direct effect of increasing SR on herbage nutritive quality but did notice a significant interaction between SR and season on sward nutritive value with greatest differences occurring during the summer and autumn grazing periods, when the sward was in its reproductive stage of growth. This resulted in enhanced sward nutritive value as SR and grazing severity increased. In regards to post-grazing sward height, Lee et al. (2008) observed crude protein (CP) to decrease and NDF and ADF concentrations to increase in the subsequent grazing rotations as post grazing sward heights increased. In addition, many studies have demonstrated the benefits of early spring grazing to low post-grazing sward heights on herbage nutritive value and utilisation levels of grazing swards in subsequent rotations (Kennedy et al., 2006; Korte et al., 1984; O'Donovan et al., 2004).

2.5 Factors affecting lamb output

The number of lambs born and subsequently weaned per ewe joined to the ram (lamb output) is widely acknowledged as a key measure of the technical efficiency of sheep production systems (Diskin and McHugh, 2012). Numerous factors influence lamb output from the breeding flock including ewe reproductive performance, nutrition, flock management, lamb survival and environmental conditions. One key determining factor of lamb output is ewe prolificacy potential defined as the number of lambs born per ewe per year (Davis et al., 2006) which is influenced by genetics, nutrition, ewe body weight and body condition and age/parity.

2.5.1 Genetics

Genetic variation in ovulation rate (the average number of eggs shed at ovulation; Scaramuzzi and Radford, 1983) in sheep has been widely reported within the literature, with substantial differences observed between and within breeds and strains of sheep (Davis, 2005; Hanrahan et al., 2004). The latter difference can be explained by the segregation of a gene with a large effect on ovarian function. In sheep, reproductive performance levels have been found to be influenced by numerous fecundity (the number of live offspring produced by an organism; Hafez and Hafez, (2000)) genes identified in a variety of breeds/strains including the Booroola merino, Romney, Lacaune, Cambridge, and Belclare. Three putative genes widely associated with increased ovulation rates include the Booroola, Inverdale and growth differentiation factor 9 gene, located on chromosomes five, six, and X in identified carrier sheep (Table 2.3; Jansson, 2014; Notter, 2012).

Table 2.3 Distribution and location of the Booroola, Inverdale and growth differentiation factor 9 (GDF) genes

Genes	Chromosome	Mutation	Breed	Distribution
Inverdale	X	FecX ^I , FecX ^H	Romney	England, New Zealand
		FecX ^G , FecX ^B ,	Belclare	Ireland
		FecX ^L	Lacaune	France
		FecX ^G , FecG ^H	Cambridge	England
Booroola	6	FecB ^B	Booroola merino	Australia
GDF 9	5	FecG ^H	Belclare	Ireland, England
		FecG ^H	Cambridge	Ireland, England

Adapted from Petrovic et al. (2012) and Mishra (2013).

2.5.1.1 Booroola gene

The Booroola gene is a dominant autosomal gene with an additive effect on ovulation rate, first identified in prolific Booroola merinos (Piper et al., 1985). It is located on chromosome six and codes for a mutation in the bone morphogenetic protein 1B receptors (Petrovic, 2012) in the ovaries and granulosa cells, with each copy of the gene having an additive effect on ewe ovulation rate. One copy of the Booroola gene increases ovulation rates by approximately 1.5 and two copies by 3.0. These extra ovulations often increase ewe prolificacy potential by 1.0 to 1.5 lambs born per ewe, respectively (Davis, 2004).

2.5.1.2 Inverdale gene

The Inverdale gene was first discovered in Romney sheep (Notter, 2012). It is located on the X chromosome and is responsible for increased prolificacy in carrier breeds such as the Romney, Belclare and Cambridge (Davis et al., 1991; Petrovic, 2012). The mode of inheritance of the Inverdale gene on the X chromosome means sires carrying the FecX¹ mutation can pass the gene onto their daughters but not their sons. However, dams carrying one copy of the gene have the ability to pass it onto half of their offspring of either sex. Davis et al. (1991) reported an increase in ovulation rate by about 1.0 egg in carrier ewes of the gene than in non-carrier ewes. Davis et al. (1998) reported Romney ewes carrying a single copy of the Inverdale gene to have a superior ovulation rate (+67%) and greater litter size (+38%) relative to non-carriers, although, homozygous ewes carrying two copies of the Inverdale gene are infertile. Thus careful breeding plans are required to avoid the birth of homozygous females.

2.5.1.3 Growth differentiation factor 9

The growth differentiation factor 9 fecundity gene is located on chromosome five and is a member of the transferring growth factor beta superfamily and codes for distinct proteins, the expression of which in ovarian tissue is exclusively in the oocyte of the developing follicle. It is expressed in the oocyte from the primary stage of follicular development until ovulation (Hanrahan et al., 2004) and has been identified in prolific sheep breeds such as the Cambridge and Belclare (Mullen and Hanrahan, 2014). Similar to the Inverdale gene, the growth differentiation factor 9 gene results in increased ovulation rate in heterozygous ewes and infertility due to streak ovaries in homozygous carriers (Hanrahan et al., 2004).

2.5.2 Cross breeding

Crossbreeding, defined as the mating of sires from one breed or breed combination to dams of another breed or breed combination in order to utilize differences between breeds is widely practiced in sheep populations globally. The use of prolific breeds to increase litter size in crossbreeding programmes is a widely adopted method of increasing productivity in lamb production systems, particularly where meat production is the main objective (Dawson and Carson, 2002). This is primarily achieved through the selection of complementarity traits of two or more breeds to exploit their genetic breed differences for economically important production traits (Afolayan et al., 2007; Cottle, 2010; Dawson and Carson, 2002). In addition crossbreeding enhances heterosis which is defined as an increase in the performance of hybrids over purebreds. This is generally associated with an increase in performance in subsequent generations of sheep in traits such as fertility, growth, and carcass characteristics (Croston and Pollott, 1994; Thomas, 2006). Reproductive traits in sheep are lowly heritable, with prolificacy having a low heritability of around 10% (Bradford, 1985; Inskeep and Goodman, 2013). However, lowly heritable traits have a high response to crossbreeding and therefore achieve the greatest levels of heterosis (Rae, 1982). Sidwell (1962) using two, three, and four breed crosses demonstrated increases in ewe prolificacy and lambing and weaning percentage over purebred breeds. Similarly Aaron (2014) reported the feasible use of terminal (two and three breed crosses) and rotational (three breed crosses) crossbreeding programs to allow for high levels of heterosis to be maintained in crossbred progeny at farm level.

The use of crossbred ewes derived from high prolific breeds (Finnish Landrace, Lleyn, and Belclare) has been demonstrated to improve prolificacy levels in ewe flocks (Notter, 2012). Lynch (2014) observed high prolific Belclare crossbred ewes to achieve a higher litter size of 1.89 compared to 1.65 in lowland Suffolk-, Texel-, Charolais-, and Cheviot crossbred ewes over a four year period. Similarly Hanrahan (1994) demonstrated using high prolific sire breeds to produce breeding females increased ovulation rates, born litter size, and weaning rates over less prolific breeds (Table 2.4).

Table 2.4 Effect of sire breed on ewe reproductive performance

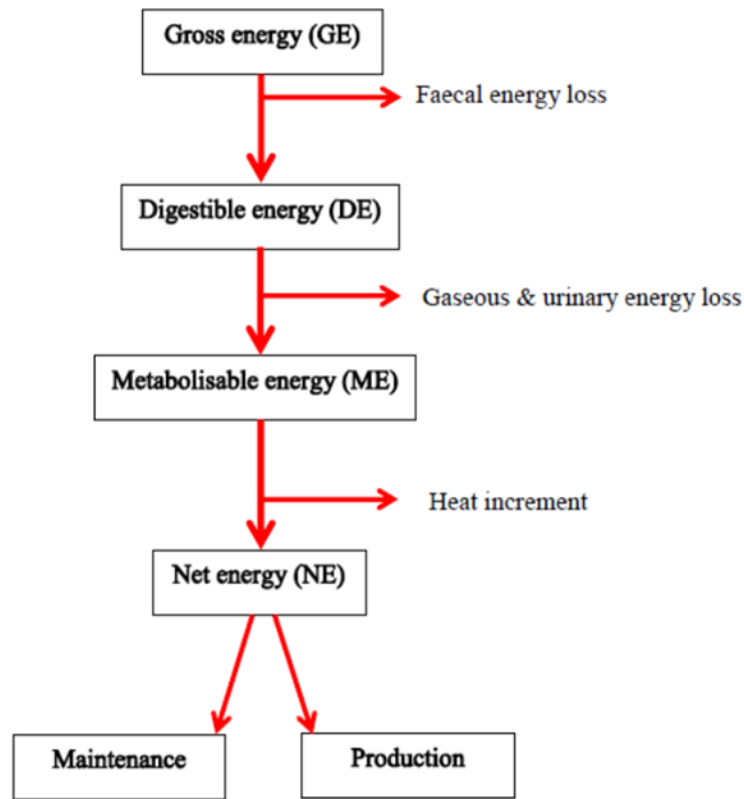
Breed	Ovulation rate	Litter size born per ewe	No. lambs reared per ewe
Belclare	1.90	1.89	1.54
Blue Leicester	1.62	1.71	1.38
Border Leicester	1.51	1.60	1.36
Cheviot	1.57	1.51	1.11
Suffolk	1.50	1.65	1.33
Texel	1.52	1.58	1.33
Galway	1.62	1.53	1.20

Adapted from Hanrahan (1994)

2.5.3 Nutrition

Nutrition influences the chain of reproductive events in the ewe due to its close alignment with feed supply (Scaramuzzi et al., 2006). The nutritional requirement of the ewe is influenced by various factors throughout the production year including; mature body size, body condition score, number of lambs born/weaned, age, and stage of production (Annett and Carson, 2006; Robinson et al., 2006). Fluctuations in energy supply and demand can have a considerably effect on a ewes performance.

The two main descriptors used for the energy requirements of ruminants are metabolisable energy (ME) and net energy (NE). The net energy is the energy available to the animal for maintenance and production (Jarrige, 1989) and is determined by subtracting energy lost to the heat increment associated with feed intake away from the ME value of the feed source. The net energy system describes the NE value of a feed stuff in two forms (Fig. 2.3), energy required for lactation (UFL) and energy required for meat production (UFV) and is calculated in UFL units, based on values outlined by Jarrige (1989). One UFL unit is equivalent to the energy content of one kilogram of standard air dried barley, with all other feed sources compared to the standard energy content of barley. The PDI system refers to the protein truly digestible in the small intestines and the PDI value of a feed is calculated from the sum of two parameters: (1) PDIA = dietary protein un-degraded in the rumen but truly digestible in the small intestine and (2) PDIM = microbial true protein that is truly digestible in the small intestine.



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960 **Figure 2.3** Breakdown of the terms used to describe the energy content of ruminant feed

961

962 The production year of the ewe can be divided into three main production stages; mating,
 963 pregnancy and lactation.

964

965 2.5.3.1 Mating

966 The plane of nutrition received by the ewe prior to and during the mating period has a direct
 967 influence on her reproductive performance levels, primarily due to the effects of nutrition on
 968 hormone production, oocyte competence and fertilisation (Borowczyk et al., 2006; Picciano,
 969 2003). During this time an elevated plane of nutrition commonly referred to as ‘flushing’
 970 allows the ewe to restore body reserves utilised during pregnancy and lactation and also
 971 reduces the likelihood of atresia of the ovarian follicles (Scaramuzzi et al., 2006). It is advised
 972 that the ewe be supplied with an elevated plane of nutrition and increasing in body condition
 973 prior to mating, with a target body condition score (BCS) of 3.5 to 4.0 at the time of mating
 974 recommended for lowland breeding ewes (Keady and McNamara, 2012).

When an animal's net nutrient requirement is less than its net intake, it is described to be in a state of positive energy balance and will store excess nutrients and/or disperse the excess nutrients as metabolic heat. This is associated with increases in leptin and insulin concentrations in the blood and increased glucose uptake prior to mating and is linked to increased folliculogenesis and ovulation rate in the ewe (King et al., 2010). However, the stimulatory effects of nutrition on folliculogenesis can often occur before there are any detectable increases in ewe body weight (acute effect) as shown in Figure 2.4, with dynamic and static effects associated with an increasing body weight or an elevated body weight per se more detectable (Scaramuzzi et al., 2005).

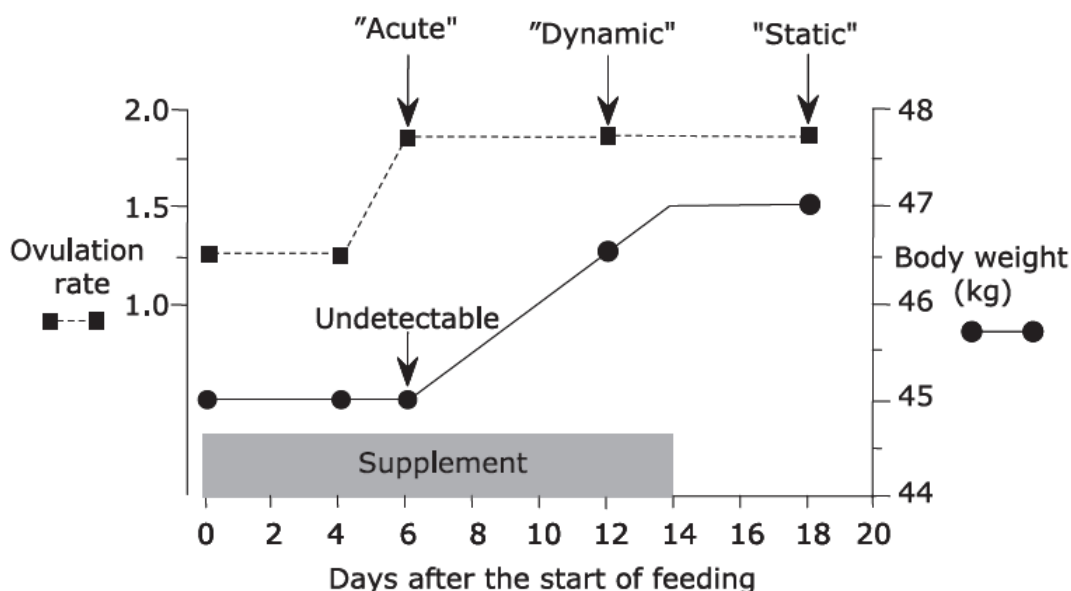


Figure 2.4 The acute, dynamic, and static influences of nutrition on ovulation rate in sheep (Scaramuzzi et al., 2006)

The NE requirements of the breeding ewe during the mating and early- to mid-pregnancy period are calculated using the following equation.

Dry period and early-pregnancy

$$\text{Maintenance energy requirement} = 0.033 \times W^{0.75},$$

Where;

W = ewe live weight (kg).

The energy requirements of the ewe during the dry period and early-pregnancy period will also be affected by any changes in body condition. The energy required to restore lost body reserves is 0.28 UFL for every 50 g/day increase in live weight. The PDI requirements for maintenance in the dry ewe are calculated by multiplying 2.50g PDI by $LW^{0.75}$ (kg).

Table 2.5 Unite fourrage laite energy requirements of the dry ewe at maintenance and gaining live weight

Parameter	Live weight gain (g per day)			
Ewe live weight	0	50	100	150
70 kg	0.80	1.08	1.36	1.64

Adapted from Jarrige, (1989)

2.5.3.2 Pregnancy

Nutrition and management of the ewe throughout the pregnancy period can have a varying effect on the number of lambs born per ewe, lamb birth weight, and perinatal ewe and lamb survival. The pregnancy period of the ewe can be divided into three distinct phases, early-, mid- and late-pregnancy.

2.5.3.2.1 Early pregnancy

Progesterone produced in the corpus luteum is an essential hormone required throughout pregnancy and it plays a key role in the preparation of the endometrium for receipt, transplantation, and nutrition of the embryo(s) in early pregnancy (Robinson, 1990; Sreenan et al., 2001). Maternal recognition of the embryo(s) takes place at approximately day 12 to 13 (Roberts and Schalue-Francis, 1990), with implantation complete by day 28 of pregnancy. In early pregnancy, ova losses can range from 20 to 30% and often results in ewes returning to oestrus and/or reductions in lambing percentage (Edey, 2013; Mackenzie and Edey 1975). Therefore, it is critical to ensure optimum ewe nutrition and management of the ewe to minimise ova losses during this time period.

Over nutrition of the ewe during the early pregnancy period can enhance metabolic rate (Parr, 1992) and increase blood flow through the liver and result in elevated levels of progesterone catabolism (Robinson, 1990; Munoz et al., 2008). Under-nutrition of the ewe during this time period has been reported to significantly affect progeny performance. Paten et al. (2012) reported under-nutrition of the ewe during this time-period to result in impaired mammary gland development and milk production in female progeny even when ewes were supplied with correct nutrition during mid- and late-pregnancy. While Munoz et al. (2008) observed a low plane of nutrition in early pregnancy to result in poor carcass conformation in male progeny compared to ewes offered maintenance level. Therefore, it is recommended that the ewe's plane of nutrition is maintained at maintenance level during this time period, to minimise early foetal losses (Robinson et al., 2002).

2.5.3.2.2 Mid-pregnancy

The mid-pregnancy period referred to as the second and third months of pregnancy in the ewe, is associated with significant increases in placenta growth which occurs from day 30 to day 100 of pregnancy. The placenta plays a vital role in the supply of nutrients from the dam to the foetus and subsequent foetal growth (Reynolds et al., 2006), with placental weight is strongly correlated to lamb birth weight (Robinson et al., 1999). Maximum placenta weight is achieved by day 90 of pregnancy however the foetus at this time is only approximately 10% of its final birth weight (Redmer et al., 2004). During this time period the ewe can afford to undergo some level of reduced nutrition, provided her nutritional requirements are adequately met in late-pregnancy (Robinson et al., 1977).

In addition, provided a ewe is at the correct target BCS at mating she can afford a loss of up to 0.5 of a BCS (Robinson, 1983; Kenyon et al., 2014), with some authors associating a decline in BCS during mid-pregnancy with increased lamb birth weight (Russel et al., 1981) as a result of increased placenta growth and subsequent increased nutrient absorption by the unborn lamb (McCrabb et al., 1992). However, severe under-nutrition during this period may hinder placenta and foetal growth in late pregnancy as a result of retarded placenta growth and nutrient supply to the foetus (Munoz et al., 2008; Redmer et al., 2004).

2.5.3.2.3 *Late pregnancy*

In the last eight weeks of pregnancy, 80% of foetal growth occurs (Robinson, 1990) with increases in foetal mass occurring in a curvilinear manner as the foetus gains 85, 50, and 25% of this final birth weight in the last 8, 4 and 2 weeks of pregnancy (Robinson et al., 1977; Robinson, 1983). Similarly mammary gland weight increases significantly in late-pregnancy from 0.5 kg to 1.4 kg and 2 kg in single and twin bearing ewes, respectively, from day 70 to day 140 of pregnancy. As ewe energy requirements rise dramatically during this time period, the intake capacity of the ewe decreases, making it difficult for the ewe to meet her nutritional requirements. This typically results in the mobilisation of body reserves, as the ewe attempts to meet the demand of pregnancy. Optimum ewe nutrition during this time period is critical for colostrum production (McGovern et al., 2015), lamb birth weight (Gao et al., 2008; Meyer et al., 2010), and early lactation performance. Adequate feeding of the ewe throughout late pregnancy should result in an increase in body weight of approximately 18% and 10% in twin and single bearing ewes, respectively (Russel, 1984).

In practice the energy requirements of the ewe in late pregnancy are seldom met, resulting in the subsequent mobilisation of body reserves (Caldeira et al., 2007) and a state of negative energy balance in the ewe (Robinson et al., 2002) in order to maintain foetal growth and mammary gland development. Increases in ewe PP can result in a significant rise in multiple foetuses pregnancies which is also associated with lower lamb birth weights. O'Doherty et al. (1997) suggested 10 kilograms as an ideal target litter weight for twin-bearing ewes. Ewes carrying multiple births have higher energy requirements than ewes carrying a single and this is a problem compounded by the limitations to voluntary feed intake as the gravid uterus compresses the rumen (Dwyer, 2005). The energy requirements of ewe during the mid- to late-pregnancy are calculated by the following equations, with the energy and PDI requirements for the ewe in late-pregnancy shown in Table 2.6.

Total energy requirement = maintenance + foetal requirements,

Foetal energy requirement = ((total energy required – maintenance requirement) ÷ 9) X 10

Table 2.6 Daily Unite fourrage laite (UFL)¹ and PDI² requirements of the ewe in late pregnancy in relation to litter size and stage of pregnancy

Ewe body weight	Litter weight	Litter size	Weeks					
			6 to 5		4 to 3		2 to 1	
			UFL	PDI	UFL	PDI	UFL	PDI
70 kg	5	1	0.88	90	1.02	114	1.22	129
	9	2	0.93	111	1.14	146	1.50	172
	11	3	0.96	121	1.24	169	1.63	188

Adapted from Jarrige, (1989)

¹UFL = Unite fourrage laite per kg dry matter

²PDI = grams

2.5.3.3 Lactation

The nutritional management of the ewe during lactation is one of the most influential factors affecting the performance of the ewe and her offspring (Rattray, 1992). In temperate grass-based lamb production systems, lambing typically coincides with the seasonal onset of grass growth (Teagasc, 2014; Bereton, 1995), with the aim to maximise lamb production from grazed grass (Keady et al., 2009). During early-lactation, ewe energy requirements peak to their highest levels in weeks three to five post-lambing (AFRC, 1993), as the ewe reaches her maximum milk yield potential (Cardellino and Benson, 2002; AFRC, 1993). Nutritional requirements of lactating ewe's vary considerably depending upon the ewe live weight, her physiological status, litter size reared, stage of lactation and diet.

During the first month of lactation, the ewe is physiologically and physically unable to consume enough feed to meet her requirements, as the capacity of her gut is greatly reduced during late-pregnancy and while hypertrophy of the gut occurs during early-lactation. Increasing rumen epithelium growth in early lactation animals has previously been reported by Liebich et al. (1987) in dairy cows. Butyric acid is a key modulator of rumen epithelium growth which occurs in response to increases in energy and protein intake (Martens et al., 2012). Research has shown increases in energy intake to result in increased rumen epithelium growth (Liebich et al., 1987; Weiss, 1994). Research by Champion et al. (2016) on impact of concentrate supplementation during early lactation of twin suckling ewes and their progeny

observed butyric acid concentration to increase in first week of lactation. This may be attributable to increasing rumen epithelium growth in response to increasing energy and protein intake. However, the ewe does not reach her full intake potential until approximately six weeks post-lambing (Gibb and Treacher, 1980; Vulich et al., 1991). This often results in the mobilisation of body reserves during this period of negative energy balance (Geenty, 1983; Jarriage, 1989). Ewes that are in the correct BCS at lambing and are grazing good quality pasture can often afford to mobilise 0.5 of a BCS and still achieve high levels of performance (Corner-Thomas et al., 2015).

The supply of sufficient quantities of high quality pasture is crucial to enhancing herbage intake and milk production during this time, with variations in nutrition often observed in fluctuations in ewe body reserves and milk yield (Corner-Thomas et al., 2015). There is a strong interrelationship between herbage availability, quality, and herbage intake of the grazing animal. Maxwell et al (1979) reported twin rearing ewes to reach a peak OMI in weeks 5 to 6 on high quality pasture. Morris and Kenyon (2004) estimated the daily grass DM intake for a twin rearing ewe to be 2.5 kg DM per day.

The nutrient requirements of the ewe during lactation is proportional to its litter growth rate, with milk production in the first four weeks of lactation estimated from the weight gain of the litter with an equation established by a water dilution technique (Bocquier, Theriez and Brelurut, 1987). In practice, on average, the requirement of the suckling ewe, above maintenance, is 0.34 UFL per day and 36 g PDI per 100 g per day litter growth rate during the first month of lactation, with the NE and PDI requirements of early lactation based upon initial ewe body reserves. Jarrige (1989) stated that ewes can be allowed to lose up to 0.5 of a BCS unit during early lactation provided they are in correct BCS at parturition (Table 2.7).

Table 2.7 Nutrient requirement for milk production in weeks 1 to 3 and weeks 4 to 6 of lactation, according to average daily gain of the litter from day 10 to 30 of lactation (assuming a drop in body condition score of 1 one over the six week period)

Ewe live weight	Litter growth rate (g per day)	1 to 3 weeks	4 to 6 weeks
70 kg	150	0.50	0.84
	250	0.80	1.04

350	1.10	1.34
450	1.55	1.74

Adapted from Jarrige, (1989)

2.5.4 Live weight

Ewe live weight (kg) has a significant impact on ewe productivity (Brown et al., 2014, Cam et al., 2010). It has a direct effect on key ewe and lamb performance traits including, conception and lambing rate, lamb birth weight, growth, and weaning weight. Numerous factors influence ewe live weight including: mature body size, age, parity, nutrition, and the physiological status of ewe. Therefore, live weight should not be used as a sole indicator of body energy reserves or the nutritional adequacy of a ewe's diet, due to variations in skeletal size within and between sheep breeds (Kenyon et al., 2014). Keady et al. (2007) highlighted the benefits of the use of BCS to overcome such variations when determining the ewe energy reserves. The measure of live weight and BCS combined allow for a more accurate assessment of ewe energy reserves (Keady and McNamara, 2012).

Acute and static effects of nutrition on ewe live weight can significantly influence ewe PP through increased ovulation rates as previously mentioned and subsequently greater numbers of lambs born in heavy ewes relative to lighter ewes, with the percentage of twin births to total births found to increase by about 6% per 4.5 kg increase in ewe live weight (Geenty, 2013). Shorten et al. (2014) reported a positive relationship between pre-mating live weight and ovulation rate, with decreased embryo survival observed at low and high pre-mating live weights. Dynamic changes in ewe live weight involve a rapid weight gain while on an elevated plane of nutrition (flushing effect) three to six weeks prior to mating and can increase ovulation rates and therefore subsequent litter size, due to increases in energy supply which stimulates reproductive hormones in the ovary (Coop, 1966; Geenty, 2013).

2.5.5 Ewe Body Condition Score

Body condition score first developed in the 1960s (Russel, 1969), is a subjective measure to assess the subcutaneous fat and muscle reserves in the animal. It is a simple and practical technique measured on a standardized scale ranging from 0 to 5, in 0.5 and 0.25 measurement

increments with 0 representing an emaciated ewe and 5 representing an animal with an extremely high fat cover (Russel et al., 1969). Assessment of ewe BCS was refined by Russel (1984), who described a four step assessment technique for body condition scoring involving (1) the assessment of the degree of sharpness or roundness of the spinous processes of the lumbar vertebrae. (2) the assessment of the degree of fat cover over the transverse processes of the vertebrae (3) the measure of muscle and fatty tissues below the transverse process and (4) the fullness of the eye muscle. Alternative methods of body condition scoring evaluate the degree of fat cover over the ribs or tail bone. It is important to ensure the assessor is well trained to ensure accuracy and reliability of BCS, as scores may vary between assessors (Phythian, 2011).

The assessment of BCS is not influenced by skeletal size, gut fill, or length unlike live weight (Kenyon et al., 2014). It is a widely acknowledged indicator of a ewe's body reserves and is a commonly used management tool in monitoring flock performance. Optimum ewe BCS targets for lowland ewes throughout the production year are as follows: mating (3.5 - 4.0), scanning (3.5), lambing (3.0) and weaning (2.5 or higher; Aliyari et al., 2012; Egan and Gottstein, 2015).

There is a strong correlation between ewe live weight and BCS. Russel (1984) observed a 13% increase in ewe live weight for every one unit increase in BCS and Hanrahan (1990) observed a 12 kg increase in ewe live weight for every one unit change in BCS. The age and physiological status of the ewe can significantly influence the correlation between ewe live weight and BCS and the rate of change (Kenyon et al., 2014). Ewe BCS has been demonstrated to have a significant effect on ovulation and conception rates and lamb birth weight (Kenyon et al., 2014). Poor ewe BCS (<2.5) at mating can negatively impact on a ewe's reproductive performance due to reductions in ovulation rate and embryo survival, a reduced litter size, and an increased lambing spread (Campion, 2016; Kenyon et al., 2014). In addition, a low BCS at lambing will result in poor ewe performance throughout lactation through reduced milk yield, lower progeny growth rates and subsequently reduce her productivity, measured typically by the weaning weight of her progeny. Aliyari et al. (2012) reported ewes in poor BCS at mating (2 – 2.5) to have shorter oestrus cycles and ewes with a BCS of >3.5 to have a reduced lambing rate and reported ewe BCS to have a significant effect on lamb weaning weights. Kenyon et al. (2012) reported greater lamb weaning live weight in

lambs born to ewes at a BCS of 2.5 to 3.0 during mid- to late-pregnancy relative to lambs born to ewes at a BCS of 2.0. This is a result of the lower level of body reserves available for mobilisation in early lactation relative to ewes at a BCS to 2.5 to 3.0.

2.6 Factors influencing lamb performance and output

2.6.1 Lamb birth weight

As litter size increases, individual lamb birth weight decreases (Black, 1983). It is calculated that the birth weight of twin lambs is 80% of the birth weight relative to singles, and 77% for triplets relative to twins (Donald and Russell, 1970; Keady and Hanrahan, 2013). Robinson et al. (1977) reported reductions in individual lamb birth weights of 19, 20 and 14% from one, to two, three, and four lambs as litter size increased in prolific crossbred ewes. As pregnancy proceeds, differences in foetal weight increase with Robinson et al. (1977) reporting a 5% reduction for each 1 lamb increase in litter size. Lamb birth weight is highly correlated to ewe live weight at mating (Black, 1983). Research has shown that for each 1.0 kg increase in lamb birth weight subsequent 12 week weight increases by 1.2 to 1.7 kg (Thomson et al., 2004) and weaning weight (14 weeks) increases by 3 to 3.4 kg (Keady et al., 2009b,c). This increase in weaning weight is due to a combination of the increase in lamb birth weight and growth rate.

2.6.2 Growth of the grazing lamb

Growth is defined as an increase in tissue mass, with the sigmoidal growth curve of an animal consisting of a prepubertal accelerating phase and a postpubertal decelerating phase (Owen et al., 1993). Lamb growth rate is primarily determined by energy intake relative to live weight. Many factors influence lamb growth rate including; birth weight (Greenwood et al., 1998; Kenyon et al., 2011), litter size (Dismoski et al 1998; Vulich et al., 1991), milk yield of the dam, parental genetics, mature body size (Donald and Russell, 1970), and diet (Fraser et al., 2004; Morgan et al., 2007).

Milk is an essential nutrient source for the growing lamb in its first 3 to 4 weeks of life (Snowder and Glimp, 1991), with growth primarily governed by the milk yield of the ewe in

the early lactation period (Forbes, 1968). During this time period live weight gain is highly correlated to milk supply (McGovern et al., 2015; Morgan et al., 2007). Treacher (1983) reported that a mean efficiency of 1 kilogram of live weight gain in the growing lamb for every 6 ± 1.4 litres of milk consumed, with variations in the efficiency of conversion primarily attributed to differences in milk composition, stage of lactation, nutrition, and litter size. It is estimated that twin lambs receive approximately 66% of the milk supply and achieve a proportional pre-weaning weight gain of 0.85 of that achieved by single lambs (Vulich et al., 1991). Keady (2010) demonstrated lamb ADG to decrease as litter size increased and reported ADG of 340, 295, and 290 g/day for single, twin and triplet lambs in a grass based system respectively.

The herbage intake of lambs is negligible in the first 3 weeks of life (Penning and Gibb, 1979), with the level of milk supply the primary influencer of the age at which grazing commences and the rate of herbage intake (Hodge, 1966; Muir et al., 2000). Twin lambs begin to consume herbage at an earlier age relative to singles and receive approximately 50% of their energy intake from pasture at 6 weeks of age compared to 22% for single lambs. As lactation progresses, grass relative to milk intake accounts for a significantly higher proportion of the lambs diet, with the availability and quality of pasture of great influence on lamb growth rate (Coop et al., 1972; Joyce and Rattray, 1970; Peart, 1982). A study by Langlands (1972) demonstrated herbage consumption to be significantly higher from week four of lactation for lambs suckling ewes of low milk yield compared to lambs suckling ewes with a higher milk yield. Maxwell et al. (1979) observed twin lambs to consume significantly more herbage per kilogram of live weight than singles from 7 to 14 weeks of age. The efficiency of the conversion of metabolizable energy to gain in lambs is 0.33 for herbage (Rattray and Joyce, 1974) and 0.71 for milk (Penning et al., 1978). Penning and Gibb (1979) estimated that herbage intake would need to increase by 4.7% for each 1% decrease in milk intake to maintain the same total net energy for gain.

2.6.2.1 Effect of ewe genotype on lamb growth

Ewe genotype can significantly influence lamb growth and lifetime performance (Cameron and Smith, 1984). A study by Gootwine et al. (2006) observed the Booroola mutation to be associated with lower birth weight, reduced growth in lambs, and lower mature body size of

the ewe. Similarly Meyer and Kirton (1984) observed significantly slower growth in crossbred lambs carrying the Booroola gene.

2.6.2.2 Effect of ewe prolificacy potential on lamb growth

Several studies (Flanagan, 2003; Keady et al., 2009; MacDonald et al., 2008) have reported SR to have a significant effect on the performance of the grazing lamb and overall output per ha in grass based ruminant production systems. Keady et al. (2009) observed lamb birth weight, growth rate, and weaning weight to decrease as SR increased from 10.5 ewes per ha to 14.4 ewes per ha over a four year period. However, despite lower individual animal performance levels, output per hectare (kg carcass) was greatest at 14.4 ewes per ha at 479.5 kg per ha compared to the lower SR of 10.5 ewes per ha which produced a carcass output of 349.5 kg per ha (Table 2.5).

Table 2.8 Effect of stocking rate on lamb performance and carcass output per hectare (kg per ha)

Parameter	10.5 ewes per ha	14.4 ewes per ha
0 to 14 weeks (g per day)	267	245
Weaning weight (kg)	30.8	27.9
Carcass output (kg per ha)	349.5	479.5

Adapted from Keady et al. (2009)

Similarly, Nolan (1972) observed a 7.4% reduction in lamb growth rate as SR increased but an increase in carcass output of 98 kg/ha when SR increased from 10 to 15 ewes per ha. Orr and Newton (1984) reported lamb growth rates to decrease and days to sale increase as SR increased, with lamb ADG's of 274, 263 and 252 g per day and days to sale of 124, 126 and 129 days observed at SR of 12, 16 and 20 ewes per ha, respectively.

2.6.3 Lamb viability and mortality

The behaviour and survival of the neonatal lamb is influenced by numerous factors including; birth weight (Everett-Hincks et al., 2005), litter size (Thomson et al., 2004), ewe parity, plane of nutrition (McGovern, 2015), dam and sire genotype (Conington et al., 2015), and environmental conditions (Dwyer et al., 2003). Increases in lamb birth weight are positively

associated with increased lamb viability particularly in multiple births (Robinson, 1981). The viability of the new born lamb and its ability to suckle is fundamental to its survival (Dwyer et al., 2003) and ensuring the neonatal lamb attains adequate quantities of colostrum soon after birth is critical to its survival.

Muir and Thomson (2009) reported lamb survival rates of 88, 86, 70, and 43% for single, twin, triplet, and quads, respectively. Macfarlane et al. (2010) observed triplet born lambs to be less vigorous than twins and required assistance to suckle. Dwyer et al. (2012) similarly observed lambs born in larger litters more likely to require assistance to suckle relative to single or twin lambs.

Lamb mortality is a major factor influencing efficiency in lamb production systems, with perinatal lamb mortality accounting for 10 to 30% of losses in lamb production systems worldwide (Dwyer et al., 2015). Most neonatal lamb mortality occurs within the first 24 hours of life, and reducing such losses is essential to the development of more efficient lamb production systems, if increased weaning rates and subsequently increased lamb carcass output are to be achieved through increases in flock prolificacy (Dwyer, 2008).

Davis et al. (1983) reported that as mean litter size increases above 1.7 lambs born per ewe, the decline in single births is offset by an increase in triplet births. Increased incidences of birth difficulty are often associated with higher litter sizes and heavier birth weights (Everett-Hincks et al., 2005; Gama et al., 1991 Maxa et al., 2009). Many authors have described a U-shaped distribution effect of lamb birth weight on lamb survival, with increased lamb birth weights associated with decreases in mortality due to starvation and exposure, particularly in multiple births (Dwyer, 2003). However, as birth weight increases the risk of death by dystocia increases particularly in single births (Fogarty, 1992). Kerslake et al. (2005) reported dystocia to account for 57% of single and 47% of multiple deaths. Morel et al. (2009) reported lamb survival to weaning to decrease as litter size increased, with birth weight a major contributing factor.

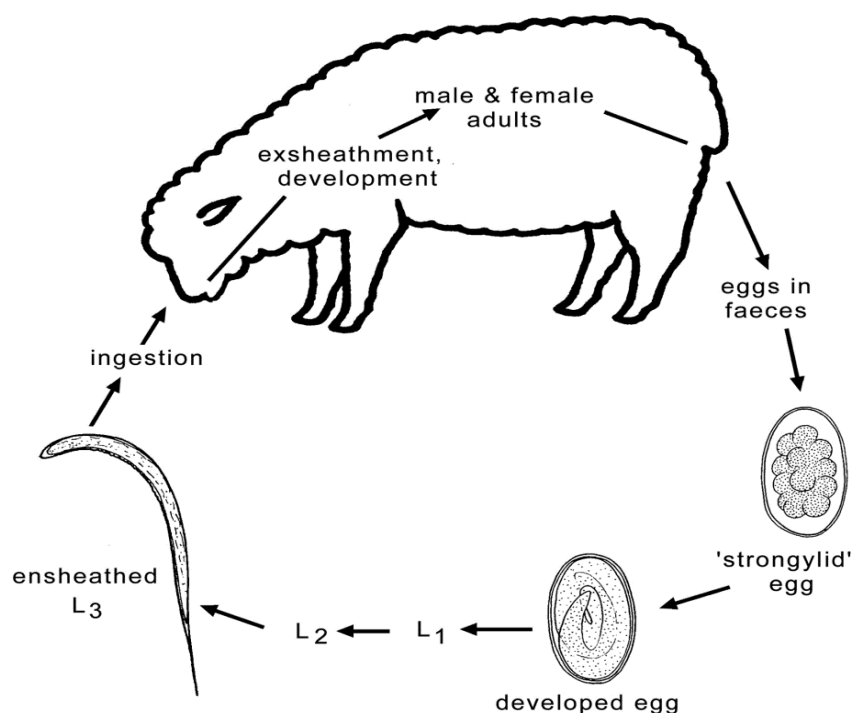
2.5.4 Gastrointestinal nematodes

Gastrointestinal nematode (roundworms) parasites are a major economic problem for sheep producers worldwide (Roeder et al., 2013). The presence and level of their infection can vary

tremendously depending on climatic and environmental conditions, age and immunological status of the animal, pasture type, and grazing management practices operated (Stear et al., 2009; Thamsborg et al., 1996). Animal productivity is greatly reduced by the insidious effects of gastrointestinal nematode infections on animal live weight, daily growth (Hynes, 2012), and reproductive performance (Anderson, 1982; Downey and Conway, 1968). Losses in animal productivity and the costs of parasite control measures substantially impact on farm profitability and are estimated to cost the global livestock industry over \$ 3 billion annually (Jackson et al., 2009).

Nematodirus and *Trichostrongylus* species are two principal gastro-nematodes found to infect small grazing ruminants in temperate grazing regions (Anderson, 1982). The basic life cycle representing gastrointestinal nematodes of affecting small ruminants is illustrated in Figure 2.5 Where nematode eggs are deposited on pasture, with larvae stage one, two and three free-living outside the host, with the life cycle completed inside the host when stage four larvae develop into adult nematodes. The lifecycle of the *Nematodius battus* species, found to typically infect lambs is slightly different to the standard lifecycle where the larvae develop into infective L3 larvae within the eggs and are hatched at temperatures above 10°C following a cold weather period typically often winter in temperate climatic regions, resulting in *Nematodius battus* outbreaks in late spring.

Animals which are most prone to parasitic infection include the young non-immune animal, immune-comprised animals, and those exposed to high infection pressures. Nematode specie populations in grazing sheep are often over-dispersed, with the majority of sheep carrying low numbers of worms and a few carrying high worm burden levels. Sources of nematode infections to the new born lamb primarily include the peri-parturient transmission of nematode eggs from the ewe and the contamination of pasture from the deposition of nematode eggs from the previous grazing season (Conway and Downey, 1968, Thamsborg et al., 1996). *Nematodirus battus* is one of the most prominent gastro-nematodes found to infect young lambs (Hynes, 2012; Denwood et al., 2008), with peak *Nematodirus* levels typically occurring in late Spring/early Summer (Downey and Conway, 1968). This often coincides with the adaption of the young lambs diet to solid feed/grazing pastures in mid-season lamb production systems. Nutrition of the ewe and her offspring and lamb growth rates are key factors influencing exposure of the developing lamb to parasites, with single lambs less prone to parasitism than twins, due to their higher milk intake levels and growth in early life (Downey and Conway, 1968).



1360

1361 **Figure 2.5** Diagrams of gastrointestinal nematodes lifecycle; First-, second-, and third-stage
 1362 larvae (L1, L2 and L3, respectively) are live freely outside the host in the environment. The
 1363 fourth larval (L4) and adult stages are parasitic in the gastrointestinal tract of the host animal.
 1364 Adapted from Demeler, (2005)

1365

1366 Greater parasitic levels and infections are often associated with increased SR, however,
 1367 scientific evidence to support this theory is limited. Thamsborg et al. (1996) observed
 1368 significantly higher faecal egg counts in lambs and ewes grazing at high SR of 17 ewes per ha
 1369 compared to animals at a medium SR of 11.5 per 12.9 ewes per ha and a low SR of 8.6 ewes
 1370 per ha. Downey and Conway, (1968) over a four year trial period, observed *Nematodirus*
 1371 infestations of pastures to increase in the third and fourth year of successive grazing years in a
 1372 sheep system and found ewes rearing twins compared to singles resulted in higher infestation
 1373 levels of *Nematodirus* species but found no effect of birth type or SR on the infestation of
 1374 other strongyles species. Downey (1969) observed lambs at higher SR to experience a higher
 1375 worm infection of *Trichstrongylus* species in October relative lambs at a low SR but no effect
 1376 on total worm burdens.

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3. Chapter Three

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Effect of ewe prolificacy potential and stocking rate on primiparous flock performance

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3.1 Abstract

The objective of this study was to investigate the effect of ewe prolificacy potential (PP; predicted number of lambs born per ewe per year) as dictated by sire breed type, stocking rate (SR; ewes per ha), and their interaction on animal performance in a primiparous flock. The study had a 2 x 3 factorial design, consisting of two ewe PP levels and three SR incorporating 360 primiparous ewes, comprising of two ewe genotypes (180 medium prolificacy potential (MP – Suffolk crossbred ewes) and 180 high prolificacy potential (HP – Belclare crossbred ewes)). Stocking rates were low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha), and high (HSR; 14 ewes per ha). There were 60 ewes per treatment and each treatment was assigned to an individual farmlet of five paddocks for the duration of the study. There was no ewe PP by SR interactions observed for ewe body weight (BW) and body condition score (BCS; $P>0.05$). Medium prolificacy potential ewes had a higher BW and BCS at initial mating, pregnancy scanning, 6 weeks post-lambing and weaning ($P<0.001$). At lambing and second mating ewe BCS did not differ by ewe PP ($P>0.05$). Lambs born to HP ewes achieved a lower average daily gain (ADG) up to 6 weeks of age, but a higher ADG from 10 to 14 weeks of age compared to MP lambs ($P<0.01$). Post-weaning, and lifetime lamb ADG, carcass traits (weight, conformation, fat score), and days to slaughter (DTS) did not differ by ewe PP. Low SR ewes had a higher BW than ewes at the MSR and HSR, which did not differ from each other at second mating ($P<0.001$). Lower lamb ADG was recorded at the MSR and HSR pre- and post-weaning ($P<0.01$) compared to LSR, with MSR and HSR lambs subsequently requiring longer to reach slaughter ($P<0.001$). Total herbage utilisation was highest at the HSR and lowest at the LSR (with the MSR not differing from either; $P>0.05$) above the post-grazing sward height of 4.0 cm pre-weaning and 3.5 cm post-weaning ($P<0.05$). Carcass output per hectare increased as both ewe PP and SR increased ($P<0.001$). In summary, Primiparous flock performance was significantly reduced as SR increased from 10 ewes per hectare to 12 ewes per hectare and 14 ewes per hectare, with no further decrease in performance from 12 to 14 ewes/ha. Increased carcass output per hectare is achievable through the use of greater ewe PP and SR levels within a temperate grass-based lamb production system.

3.2 Introduction

Primiparous ewes have a lower level of productivity in the breeding ewe flock compared to multiparous ewes (Annett et al., 2010), with primiparous ewes having lower body weights at breeding (Annett et al., 2010; Coop, 1962), reproductive performance (Annett et al., 2010; Thomson et al., 2004), lamb birth weights, and subsequent progeny growth rates (Annett et al., 2010). Most of these studies tended to focus on the difference between primiparous and multiparous ewes rather than the difference within primiparous ewes in a temperate grass-based lamb production system.

Prolificacy is defined as the number of lambs born per ewe per year (Davis et al., 2006), with the use of prolific ewe genotypes providing producers with an opportunity to increase ewe prolificacy through outcrossing breeding programs (Thomson et al., 2004). Increases in flock prolificacy have been shown to significantly increase production (Keady et al., 2009) but it is also often associated with greater numbers of multiple litters (Hinch et al., 1985), reduced progeny birth weights (Keady et al., 2009), growth rates, and weaning weights (Snowder and Glimp, 1991).

Stocking rate (SR) is defined as the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time (ewes per ha; Allen et al., 2011). It determines the amount of herbage available per animal and is a key determinant of productivity in grass-based production systems (Keady et al., 2009). Increased SR is commonly associated with higher output supported by increased herbage production and utilisation (Macdonald et al., 2008; McCarthy et al., 2012a), however this is frequently achieved at the expense of individual animal performance (Stakelum and Dillon, 2007).

Previous studies have reported effects of ewe PP and SR on individual ewe and lamb performance (Dawson and Carson, 2002; Keady et al., 2009; Morris and Kenyon, 2004); however, limited information has been reported on the potential implications of both ewe PP and SR on primiparous ewe and lamb performance. Therefore the objective of the present study was to evaluate the effect of ewe PP, SR, and their interaction on primiparous ewe and progeny performance in a temperate grass-based lamb production system.

3.3 Material and methods

The study was conducted at the Sheep Research Demonstration Farm, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co Galway, Ireland (54° 80'N; 7°25'W), from October 2011 to December 2012. The soil type was a free draining mineral texture. The area used for the study predominantly consisted of perennial ryegrass (*Lolium perenne* L.) swards, with low levels of white clover (*Trifolium repens*), *Agrostis* spp. and *Poa* spp. also present.

3.3.1 Study design and animals

The study had a 2 x 3 factorial design, consisting of ewes with two ewe prolificacy potentials (PP; predicted number of lambs born per ewe per year) managed at three SR. A total of 360 primiparous ewes (2 years (\pm 1 month) of age at lambing) comprising of two ewe genotypes were assembled in 2011. This included 180 medium prolificacy potential (MP – Suffolk crossbred ewes) and 180 high prolificacy potential ewes (HP – Belclare crossbred ewes). Ewes within each ewe PP level were blocked at post pregnancy scanning based on body weight (BW; kg), body condition score (BCS), and scanned litter size, before being randomly assigned to one of three SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) and high (HSR; 14 ewes per ha). All ewes remained in their allocated treatment for the duration of the study unless they were culled or died, in which case a replacement primiparous ewe and her lambs, as appropriate, were added.

A total land area of 30.6 hectares of grassland was used for the duration of the study. This area was divided into five blocks based on location within the farm, soil type, and pasture age; each block was further divided into six paddocks, with one paddock per block randomly assigned to each treatment, resulting in six independent farmlets. Total land area for each LSR, MSR and HSR was 6.0, 5.0, and 4.3 hectares, respectively. Farmlets were managed in a five paddock rotational grazing system. Inorganic fertiliser application rates were kept constant for each treatment and were applied at: 150 kg nitrogen (N), 20 kg phosphorus (P), 45 kg potassium (K) per hectare per year, respectively. Nitrogen was applied after grazing rotations two to six at an average rate of 25 kg N per ha, with P and K applied in two applications, the first in early summer and second in the autumn period. Lime was applied at a rate of 4900 kg per hectare in the autumn of 2011. Farm cover (forage mass; kg dry matter

(DM) per ha) was estimated weekly using the quadrat and shears method (O'Donovan et al., 2002) and recorded on Pasturebase, (a grass budgeting management tool; Pasturebase Ireland, National Grassland Database, Oak Park, Co, Carlow, Ireland) with grazing management decisions based on grass budget information and daily target post-grazing sward heights. Target pre-grazing sward heights were 7.0 to 9.0 cm (1200 to 1500 kg DM per ha) across all treatments, with a target post-grazing sward height pre-weaning (March to June) of 4.0 cm. Post-weaning (July to December) a first to last stocking system (Allen et al., 2011) was operated, with target post-grazing sward heights of 5.5 (lambs) and 3.5 cm (ewes). Paddocks were split using a temporary electric fence from the second grazing rotation once herbage availability above target post-grazing sward height exceeded four days. Twenty percent of each farmlet area was closed for silage in mid to late April, once grass supply exceeded flock demand (minimum farm cover 50 kg DM per ewe per ha). In order to maintain sward quality, surplus grass was removed as baled silage or paddocks were mechanical topped to 3.5 cm at least once during the main grazing season.

3.3.2 Flock management

All ewes were mated to Charollais rams over a 6 week period in October and November 2011. Ewes were housed and offered baled grass silage (70% dry matter digestibility (DMD) as determined by laboratory analysis prior to the feeding period commencing) *ad libitum* in early December and were pregnancy scanned 90 days after the mating start date. Concentrate supplementation was introduced to ewes during late pregnancy with concentrate feed levels based on silage quality and ewe energy requirements (AFRC, 1993) which varied by scanned litter size. Supplementation was introduced to 6 weeks prior to predicted lambing start date with twin bearing ewes receiving a daily concentrate feed allowance of 0.2 kg of concentrates. Daily concentrate feed levels increased every 14 days at a rate of 0.2 kg up to 0.6 kg of concentrates per day at the point of lambing, with singles receiving 30% less and triplets 30% more. Lambing commenced on the 5th of March 2012 and ended on the 28th of March 2012, with a mean lambing date of the 16th of March 2012. Post-lambing, ewes and lambs were turned out to pasture, weather permitting within 24 to 36 hours, without concentrate supplementation. When weather conditions were unfavourable ewes and lambs were housed in group pens until conditions allowed for turnout. Lambs were weaned on average at 14 weeks of age and were drafted for slaughter to produce a target carcass weight of 20 kg. As

lambs mature the proportions of bone and gut fill increase, which contributes to a decreasing dressing proportion. Therefore an increase in slaughter live weight was required as the season progressed as follows: 42, 43, 44, 45, and 46 kg in the months June, July, August, September and October, respectively. Lambs that were not slaughtered by October in each treatment were housed when grass supply dropped below 50 kg DM per ewe per ha or lamb growth rate dropped below 100 grams per day and finished on grass silage *ad libitum* and concentrate supplementation.

3.3.3 Animal measurements

Ewe BCS measured on a one to five point scale at 0.25 intervals (one=emaciated and five=over fat; Jefferies, 1961) and BW were recorded at first mating, pregnancy scanning, lambing, 6 weeks post-lambing, weaning, and second mating. All lambs were tagged, weighed and matched to their dams within 24 hours of birth. Birth date, litter size, and gender were also recorded. Lamb mortality (defined as alive or dead) within the first 24 hours, pre-weaning and total was recorded. Lambs were weighed at 2 week intervals from 6 weeks of age to slaughter and average daily gain (ADG) calculated accordingly;

PRW (pre-weaning) ADG = live weight minus birth weight divided by age at date weighed.

PTW (post-weaning) ADG = drafting live weight minus weaning live weight divided by days post-weaning.

LT (lifetime) ADG = drafting live weight minus birth weight divided by number of days required to reach slaughter which was calculated as the difference from birth date to slaughter date.

The number of days required to reach slaughter (DTS) was calculated as the number of days from birth to slaughter. Carcass conformation was scored using the EUROP grid system (E = best and P = poor) and external fat score was scored using a one to five scoring system in order of increasing fatness (Hickey et al., 2007). Dressing proportion was calculated for each lamb as cold carcass weight divided by the pre-slaughter live weight.

3.3.4 Grassland measurements

Pre-grazing herbage mass (>3.5 cm) was determined prior to grazing for each paddock by harvesting a strip (1.2 m x 10 m) of grass with an Etesia mower (Etesia UK Ltd., Warwick, UK). All mown herbage from the strip was collected and weighed with a 0.1 kg (fresh weight) subsample taken and dried for 16 hours at 90 °C for the calculation of DM content. Ten compressed sward height (CSH) measurements were recorded before and after harvesting of the cut strip using a rising pasture plate meter with a steel plate (Jenquip, Fielding, New Zealand). Based on the aforementioned measurements, sward density was calculated as forage mass (kg DM/ha)/(pre-cutting – post-cutting CSH); and expressed as kg DM per cm per hectare (Delaby and Peyraud, 1998). Pre- and post-grazing CSH was also determined on each paddock before and after grazing by taking between 30 and 50 measurements across the diagonal of the paddock. The average paddock pre-grazing herbage mass above a cutting height of 3.5 and 4.0 cm was then calculated according to the following formula: Pre-grazing herbage mass = ((Pre-grazing CSH (cm) – 3.5 cm) x sward density); kg of DM per cm per ha. Herbage utilized at each grazing was also calculated as; herbage utilized (above the post-grazing CSH)/pre-grazing herbage mass (>3.5 cm) at each grazing (McCarthy et al., 2012b). Total herbage utilisation = Sum of the proportion of herbage utilised at each grazing over the pre- and post-weaning time periods relative to herbage produced (>3.5cm).

3.3.5 Chemical analyses

Dried herbage samples used to calculate DM content were used for quality determination. Samples (n = 36) were bulked based on treatment by grazing rotation (6 rotations per treatment) and analysed for DM, ash, neutral detergent fibre (NDF; Van Soest, 1963), acid detergent fibre (ADF), crude protein (CP; Leco FP-428; Leco Australia Pty Ltd., Baulkham Hills, NSW, Australia), and organic matter digestibility (OMD; Morgan et al., 1989).

3.3.6 Statistical analyses

Ewe BW, BCS, litter size, and litter live weight born and weaned per ewe were analysed using a linear mixed model in PROC HP MIXED (SAS, 2012) with ewe included as a random effect and ewe PP, SR, date weighed, and the interaction between ewe PP and SR included as fixed effects. For the binary traits lamb mortality (at birth, pre-weaning and total) and ewe culling rate, the log of the odds were modelled using logistic regression in PROC GENMOD

(SAS, 2012) with ewe PP and SR included as fixed effects. Odds ratios were calculated as the exponent of the model solutions. Lamb live weight, ADG, and carcass traits were modelled using linear mixed models in PROC HP MIXED, with ewe included as a random effect and ewe PP, SR, the interaction between ewe PP and SR, sex, and the lambs deviation in age from the treatment mean included as fixed effects. Pre- and post-grazing sward height, pre- and post-grazing herbage mass, herbage production, utilisation, and quality were analysed using linear mixed models in PROC HP MIXED, with ewe PP, SR, and the interaction between ewe PP and SR, rotation included as fixed effects in the model. For all traits, where an interaction existed between ewe PP and SR, orthogonal contrasts were used to compare differences between ewe PP within SR.

3.4 Results

3.4.1 Pasture measurements and herbage production

Mean monthly temperature, rainfall, and grass growth data for 2012 and the 30 year average (1982 to 2012) are presented in Table 3.1. Total rainfall in 2012 was 75.8 mm higher than the 30 year recorded average, with June (+ 96 mm), July (+ 31 mm) and December (+ 30 mm) being particularly wet months. In 2012, mean daily temperatures were 0.1 °C warmer than the 30 year average. Average monthly grass growth rates ranged from 4 to 79 kg DM per hectare per day, with a mean grass growth rate of 30.4 kg DM per hectare per day for 2012.

Pre- and post-grazing herbage mass, herbage utilisation (Table 3.2), grazing, and total herbage production or herbage quality (Table 3.3) did not differ by ewe PP. During the pre-weaning period SR had no effect on pre- and post-grazing herbage mass and herbage utilisation. Post-weaning the LSR ($P<0.01$) had a higher post-grazing herbage mass than the MSR and HSR. Herbage utilisation post-weaning was lowest at the LSR ($P<0.01$) relative to the MSR and HSR. A higher total herbage utilisation ($P<0.05$) was recorded at the HSR compared to the LSR, with the MSR not differing from either. Total herbage and grazing herbage yields did not differ by SR (Table 3.3). Conserved herbage yields were highest in the HP system ($P<0.001$) and were highest in the LSR, intermediate in the MSR and lowest in the HSR ($P<0.001$). With the exception of herbage CP content, SR had no effect on herbage quality (Table 3.3). The MSR had a higher CP content relative to the LSR ($P<0.05$).

3.4.2 Animal performance

The average scanned litter size achieved across the two ewe PP levels ($P<0.05$) was 1.87 (MP) and 2.06 (HP). The proportion of single and multiple litters was 0.16 and 0.84 in the MP and 0.14 and 0.86 in the HP groups. The average number of lambs weaned per ewe ($P<0.05$) was 1.66 (MP) and 1.80 (HP). The proportion of lambs that were not drafted by October was 0.11 and 0.17 for the MP and HP groups and 0.10, 0.08, and 0.23 for the LSR, MSR, and HSR groups, respectively. The predicted probability of finishing lambs from grass by mid-October was 0.93 and 0.82 for MP and HP groups ($P<0.001$) and 0.94, 0.96, and 0.82 for the LSR, MSR, and HSR, respectively ($P<0.001$).

3.4.2.1 Ewe body weight and body condition score

There were no ewe PP by SR interactions observed for ewe BW and BCS at all measured time-points ($P>0.05$). The effects of ewe PP and SR on ewe BW and BCS at key time points throughout the production year are shown in Table 3.4. With the exception of BCS at lambing and second mating, which were unaffected by ewe PP, ewe BW and BCS were higher ($P<0.001$) for MP than HP ewes at initial mating, pregnancy scanning, 6 weeks post-lambing, and weaning.

At 6 weeks post-lambing LSR ewes had a lower BCS ($P<0.001$) compared to MSR and HSR ewes, with MSR ewes also having a higher BCS compared to HSR ewes. At weaning; MSR ewes had a lower BCS ($P<0.001$) compared to the LSR and HSR ewes. At second mating MSR ewes had a lower BCS ($P<0.01$) compared to the LSR and HSR ewes. At 6 weeks post-lambing SR had no effect on ewe BW. At weaning; ewe BW was greatest at the LSR, lowest at the MSR and intermediate at the HSR ($P<0.001$) At second mating LSR ewes had a higher BW ($P<0.001$) compared to MSR and HSR ewes. Ewe culling rate did not differ by ewe PP or SR ($P>0.05$).

3.4.2.2 Pre-weaning lamb performance

Individual lamb birth weight, weaning body weight (Table 3.5), total litter birth weight per ewe (8.1 (MP) v 8.4 kg (HP)), and lamb mortality did not differ by ewe PP ($P>0.05$). Medium prolificacy lambs had a higher ADG ($P<0.01$) from birth to 6 weeks of age. However, from 10 to 14 weeks the HP lambs achieved a higher ADG ($P<0.01$).

From 6 to 10 weeks of age, MSR lambs had a lower ADG ($P<0.001$) compared to LSR and HSR lambs. Low SR lambs achieved a higher ADG from birth to weaning ($P<0.01$) compared to the MSR and HSR lambs. This was reflected by LSR lambs recording a higher ($P<0.01$) weaning weight compared to the MSR and HSR lambs. Total litter live weight weaned per ewe (47.8 and 46.9 for the MP and HP groups and 50.1, 46.4, and 45.5 kg for the LSR, MSR, and HSR groups) did not differ with ewe PP or SR ($P>0.05$).

A ewe PP by SR interaction was observed for lamb ADG from 10 to 14 weeks of age, with HP lambs achieving an 8.4 g/day SE = 1.5 lower ADG ($P<0.001$) at the HSR but a higher ADG at the LSR and MSR (Figure 3.1).

3.4.2.3 Post-weaning lamb performance and carcass output

There was no ewe PP by SR interactions observed for post-weaning lamb performance (Table 3.6). Post-weaning and LT lamb ADG, drafting weight, or carcass traits (weight, conformation, fat score) did not differ by ewe PP ($P>0.05$). High prolificacy lambs recorded a higher dressing proportion (+0.01; $P<0.05$).

Post-weaning lamb ADG was highest at LSR and lowest at the HSR ($P<0.05$), with MSR lambs not differing from either the LSR or HSR lambs. Low SR lambs achieved a higher LT ADG ($P<0.001$) compared to the ADG of the MSR and HSR lambs. This resulted in LSR lambs reaching slaughter earlier ($P<0.001$) compared to MSR and HSR lambs, however SR did not influence lamb drafting weight or carcass traits.

Carcass output was highest for the HP system at 420 kg per hectare ($P<0.001$) compared to the MP system which produced a carcass output of 385 kg per hectare and increased as SR increased with the LSR, MSR and HSR producing 336, 404, and 467 kg per hectare ($P<0.001$) all of which significantly differed from each other.

3.5 Discussion

Primiparous ewe performance has been shown to be inferior to that of multiparous ewes in the breeding ewe flock, with limited information available on the combined effect of ewe PP and SR on primiparous ewe and progeny performance in temperate grazing lamb production systems. This study therefore focused on assessing the effect of ewe PP, SR, and their interaction on primiparous ewe and progeny performance in a grass-based lamb production system.

3.5.1 Herbage production, utilisation and quality

Pasture production has previously been demonstrated to linearly increase as SR increases when fertiliser is applied at a constant rate per hectare (Macdonald et al., 2008). In the present study total herbage and grazing herbage yields did not differ by ewe PP and SR, with total herbage yields similar to that achieved by McCarthy et al. (2012a), who also reported no effect of SR on herbage yields when applying a constant rate of fertiliser.

Increased herbage utilisation in intensive grass-based production systems is often associated with increased SR levels (Macdonald et al., 2008). The higher herbage utilisation achieved at the MSR and HSR during the post-weaning period is a result of the increased herbage demand per hectare and significantly lower post-grazing sward residuals. This finding further illustrates the relationship between SR and post-grazing herbage mass on the proportion of herbage utilised per hectare reported by Macdonald et al. (2008) and McCarthy et al. (2012b).

3.5.2 Ewe body weight and body condition score

The BW of the breeding ewe has been shown to fluctuate throughout the production year and is considered a reflection of her nutritional and physiological status (Adams et al., 2007). During early lactation energy demand significantly increases as the ewe commences milk synthesis and supports the growth of her offspring. Geenty (1983) observed a state of negative energy balance in the grazing ewe in early lactation, irrespective of milk production and nutrition. Peart et al. (1975) reported the extent of BW loss in early lactation to be greatest in ewes rearing multiple litters. In the current study, the loss in BW and BCS experienced by the MP and HP ewes from pregnancy scanning to 6 weeks post-lambing suggests both ewe PP groups experienced a period of negative energy balance in the first 6 weeks of lactation. The

greater loss of body reserves experienced by the HP ewes is a probable effect of the 0.14 higher litter size reared per ewe and subsequently higher energy demand of lactation (Vulich et al., 1991).

Increasing SR is associated with reduced herbage availability in grass-based production systems as a result of increased maintenance requirements on a per hectare basis (Baudracco, et al., 2010; Macdonald et al., 2008). The lower BW of the MSR and HSR ewes at weaning indicates ewes were mobilising a greater proportion of BW during the pre-weaning period in order to meet their energy requirements (McDonald et al., 2011). This demonstrates a potential negative effect of increasing SR above 10 ewes per hectare on the BW of the primiparous ewe in a grass-based lamb production system and supports previous findings of reductions in animal BW as SR increases as a result of increased grazing competition in grass-based production systems (Gibb et al., 1981) despite having a pasture allowance between 3.89 to 5.65 kg DM per ewe and lamb unit per day, with a metabolisable energy content of 11.5 ME (MJ/kg DM) during this time period. Subsequently ewes began to recover losses in body reserves sustained during early lactation, with ewe BCS at second mating within the recommended range of 3.0 to 3.5 (Kenyon et al., 2014). It is reasonable to suggest therefore that there was no long term adverse effect of higher ewe PP or SR levels on the ability of the primiparous ewe to recover losses in body reserves sustained during the pre-weaning period.

3.5.3 Pre-weaning lamb performance

Ewe milk production is considered a key determinant of pre-weaning lamb performance, with a strong relationship reported between milk production in early lactation and lamb growth rate (McGovern et al., 2015). The lower ADG achieved by the HP lambs from birth to 6 weeks of age can be attributed to the greater litter size reared per ewe and subsequent increased competition for milk supply in early lactation (McGovern et al., 2015). A study by Galvani et al. (2014) observed lambs to increase their dry matter intake of solid feed when milk supply was lower than requirements in the first 6 weeks of lactation in order to compensate for the reduction in milk supply. The higher ADG of the HP lambs from 10 to 14 weeks of age in this study suggests these lambs may have been consuming a greater proportion of pasture to meet their energy requirements and demonstrates the ability of progeny born to HP primiparous ewes to compensate for a lower growth rate from birth to 6 weeks of age.

As lambs begin to consume herbage from 6 weeks of age (Muir et al., 2000) grazing competition between ewes and lambs for available herbage significantly increases. The lower ADG from birth to weaning and weaning weight achieved by the MSR and HSR lambs, follows a similar trend to that observed with ewe BW and BCS in the current study. This reduction in lamb performance illustrates the relationship between SR and herbage availability and indicates further effects of increasing SR above 10 ewes per hectare on primiparous flock performance. Such effects can be seen in the ewe PP by SR interaction for lamb ADG from 10 to 14 weeks, where HP lambs achieved a lower ADG compared to their MP counterparts at the HSR as a result of the greater number of lambs supported in the HP treatment.

3.5.4 Post-weaning lamb performance and carcass output

In intensively stocked grass-based production systems the age at which lambs reach target drafting weight is of great importance due to the seasonal pattern of grass growth and hence feed supply (Keady et al., 2009). The lower post-weaning ADG and subsequent greater DTS recorded by primiparous progeny in the MSR and HSR, resulted in a longer period of high pasture demand, which was reflected in the higher proportion of herbage utilised during the post-weaning period of this study. This supports previously reported reductions in individual animal performance with increasing SR in pasture-based production systems (Macdonald et al., 2008; McCarthy et al., 2012b) and indicates the effects of increasing SR on primiparous flock performance experienced during the pre-weaning period, continue post-weaning. Market requirements for lamb carcasses require a 16 to 21 kg carcass, conformation E to R (Good) and fat score 2 to 3 (Hickey et al., 2007; McHugh, 2012). All lambs in this study met market requirements illustrating the potential to operate higher ewe PP and SR systems with no negative effect on carcass quality. The 9% increase in carcass output as PP increased and 20%, and 39% more carcass produced per hectare as SR increased from the LSR to MSR, and HSR in the study demonstrates the potential to increase carcass output through the use of prolific ewe genotypes and the efficiency of increasing ewe PP and SR in a grass-based lamb production.

3.6 Conclusion

Primiparous ewe and lamb performance was significantly reduced as SR increased from 10 ewes per hectare to 12 ewes per hectare and 14 ewes per hectare in a temperate grazing lamb production system, as a result of lower herbage availability particularly during the post-weaning period. However, surprisingly no further decrease in performance occurred when SR increased from 12 to 14 ewes per hectare. Prolificacy potential of the primiparous ewe significantly influenced lamb growth in the first 6 weeks of life but not thereafter. The presence of ewe PP by SR interactions illustrated potential limits to increasing both ewe PP and SR levels on primiparous flock performance in a grass-based lamb production system. The increases in carcass output per hectare in this study demonstrates the potential to increase output per hectare through the use of greater ewe PP and SR levels within a grass-based lamb production system. Further investigation is required into the longer term effects of increasing ewe PP and SR on animal performance and herbage utilisation in temperate grass-based lamb production systems.

3.7 Acknowledgements

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Table 3.1 Average daily temperature (°C), rainfall (mm) for each month during 2012 and for the 30 year recorded average (1982 to 2012) and grass growth (kg DM per ha per day) for 2012 in Athenry

Month	Average daily temperature (°C)		Average daily rainfall (mm)		Average daily grass growth rates (kg DM per ha per day)
	2012	30 yr.	2012	30 yr.	2012
January	6.7	5.3	131.1	116.7	-
February	7.2	5.5	62.3	87.8	11.0
March	8.5	7.0	30.5	94.7	30.0
April	na	8.7	74.8	72.0	44.0
May	11.1	11.4	48.2	75.3	77.0
June	12.9	13.8	175.6	79.6	79.0
July	14.1	15.6	117.9	86.5	56.0
August	15.4	15.4	114.2	107.8	37.0
September	12.1	13.3	101.4	100.3	27.0
October	8.1	10.3	127.7	128.9	4.0
November	5.8	7.5	131.8	120.3	-
December	5.4	5.6	153.2	123.2	-
Total	-	-	1269	1193	-

2639 **Table 3.2** Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on pre- and post-grazing herbage characteristics (kg DM per ha
2640 unless stated otherwise)³

Period	PP			SR				P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Pre-weaning										
Pre-grazing mass	1554	1479	80.9	1481	1477	1591	53.3	NS	NS	NS
Post-grazing mass	293	229	27.7	274	272	239	33.9	NS	NS	NS
Herbage utilisation	0.78	0.80	0.03	0.77	0.77	0.84	0.03	NS	NS	NS
Post-weaning										
Pre-grazing mass	1561	1500	68.4	1535	1452	1605	64.3	NS	NS	NS
Post-grazing mass	110	130	18.2	189 ^a	73 ^b	97 ^b	25.2	NS	**	NS
Herbage utilisation [†]	0.92	0.91	0.02	0.85 ^a	0.95 ^b	0.94 ^b	0.04	NS	**	NS
Total herbage utilisation ^{4†}	0.86	0.85	0.03	0.81 ^a	0.86 ^{ab}	0.89 ^b	0.03	NS	*	NS

2641 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

2642 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

2643 ³kg DM per ha = kilograms of dry matter per ha.

2644 [†]= Proportion of herbage utilised.

2645 ⁴Total herbage utilisation = Sum of the proportion of herbage utilised at each grazing over the pre- and post-weaning time periods relative to
2646 herbage produced (>3.5cm).

2647 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

2648 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

2649

2650 **Table 3.3** Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on grazing, silage and total herbage production and quality of the
 2651 grazed herbage

Herbage production (kg DM per ha) ³	PP			SR				P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PP×SR
Grazing	9 431	8 646	611.8	8 173	8 779	10 165	749.3	NS	NS	NS
Silage	1 394	1 647	0.4	1 923 ^a	1 504 ^b	1 133 ^c	0.5	***	***	NS
Total	10 825	10 291	611.8	10 093	10 283	11 299	749.3	NS	NS	NS
Herbage quality (g per kg DM) ⁴										
Crude protein	200	204	7.7	185 ^a	220 ^b	200 ^{ab}	9.2	NS	*	NS
OM digestibility	769	772	1.2	773	774	764	1.4	NS	NS	NS
Neutral detergent fibre	445	445	9.9	454	446	425	11.8	NS	NS	NS
Acid detergent fibre	248	253	5.0	254	252	246	6.0	NS	NS	NS
Ash	83	87	2.5	86	85	83	3.0	NS	NS	NS

2666 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

2667 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

2668 ³kg DM per ha = kilograms of dry matter per ha.

2669 ⁴g per kg DM = grams per kilogram of dry matter.

2670 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

2671 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

2672 **Table 3.4** Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on ewe body weight and body condition score at key time points
2673 throughout the production year

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Body weight (kg)										
Mating (First)	77.5	74.3	0.62	-	-	-	-	***	-	-
Pregnancy scanning	80.8	71.2	0.60	-	-	-	-	***	-	-
6 weeks post-lambing	74.4	66.4	0.63	69.4	70.3	71.5	0.77	***	NS	NS
Weaning	75.4	67.4	0.63	73.7 ^a	69.1 ^b	71.3 ^c	0.78	***	***	NS
Mating (Second)	76.7	69.1	0.63	74.9 ^a	71.1 ^b	72.6 ^b	0.77	***	***	NS
Body condition score (1 - 5 index scale)										
Mating (First)	4.1	4.0	0.02	-	-	-	-	***	-	-
Pregnancy	3.5	3.4	0.02	-	-	-	-	***	-	-
Lambing	3.5	3.8	0.03	-	-	-	-	NS	-	-
6 weeks post-lambing	3.0	2.8	0.02	2.8 ^a	3.0 ^b	2.9 ^c	0.03	***	***	NS
Weaning	3.4	3.1	0.02	3.3 ^a	3.2 ^b	3.3 ^a	0.03	***	**	NS
Mating (Second)	3.1	3.1	0.02	3.2 ^a	3.0 ^b	3.1 ^a	0.03	NS	**	NS

2674 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

2675 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

2676 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

2677 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 3.5 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lamb birth weight, pre-weaning lamb average daily gain (ADG)³ and weaning body weight (BW)⁴

Parameter	PP			SR				P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Birth weight (kg)	4.4	4.4	0.06	-	-	-	-	NS	-	-
ADG (g per day)										
Birth to 6 weeks	275	261	3.79	272	265	268	4.57	**	NS	NS
6 to 10 weeks	256	257	3.70	267 ^a	243 ^b	258 ^a	4.60	NS	***	NS
10 to 14 weeks	230	252	5.05	248	240	235	6.17	**	NS	***
Birth to weaning	254	255	3.00	263 ^a	249 ^b	251 ^b	3.21	NS	**	NS
Weaning BW (kg)	32.6	32.1	0.33	33.5 ^a	31.6 ^b	32.0 ^b	0.40	NS	**	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³ADG = average daily gain (g per day).

⁴BW = body weight.

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

2688 **Table 3.6** Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on post-weaning and lifetime lamb average daily gain (ADG)³, days
2689 to slaughter and carcass traits

Parameters	PP			SR				P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Post-weaning ADG	203	204	4.4	217 ^a	207 ^{ab}	197 ^b	5.4	NS	*	NS
Lifetime ADG	235	229	3.1	244 ^a	225 ^b	227 ^b	3.8	NS	***	NS
Days to slaughter	178	185	2.7	171 ^a	184 ^b	189 ^b	3.3	NS	***	NS
Drafting weight (kg)	44.7	44.7	0.41	44.1	44.9	45.1	0.46	NS	NS	NS
Carcass weight (kg)	19.6	19.7	0.15	19.6	19.5	19.8	0.17	NS	NS	NS
Carcass conformation	2.8	2.8	0.22	2.8	2.8	2.8	0.04	NS	NS	NS
Carcass fat	2.9	3.0	0.04	3.0	2.9	3.0	0.04	NS	NS	NS
Dressing proportion	0.43	0.44	0.003	0.44	0.43	0.44	0.004	*	NS	NS

2690 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

2691 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

2692 ³ADG = average daily gain (g per day).

2693 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

2694 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

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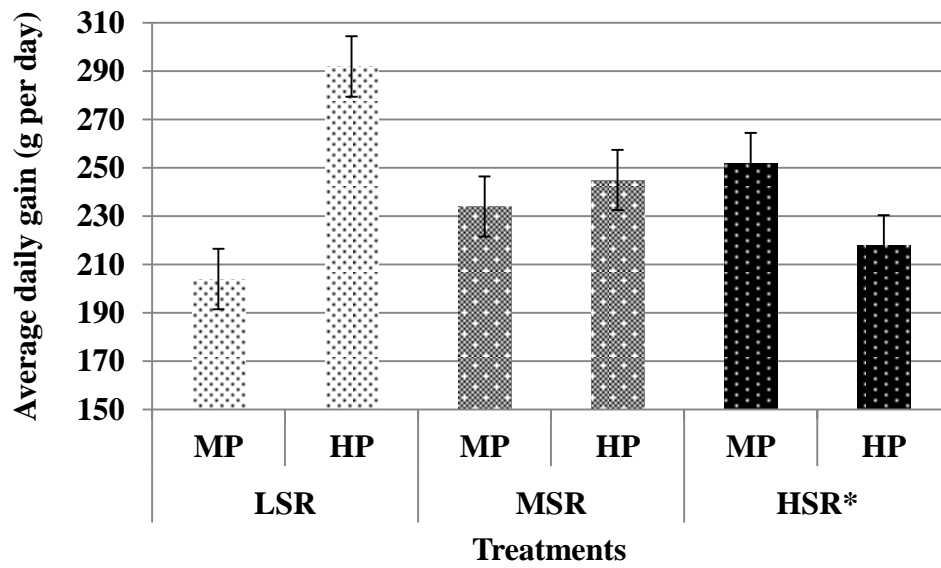


Figure 3.1 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lamb ADG from 10 to 14 weeks (error bars denote standard errors), ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential. ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha, * = Significant interaction (P<0.001)

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4. Chapter four

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**Effect of ewe prolificacy potential and stocking rate on ewe
and lamb performance in a grass-based lamb production
system**

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4.1 Abstract

The objective of the present study was to investigate the effect of ewe prolificacy potential (PP; predicted number of lambs born per ewe per year) as dictated by sire breed type, stocking rate (SR; ewes per ha), and their interaction on ewe and lamb performance in a temperate grass-based lamb production system. The study was a 2 x 3 factorial design, consisting of two differing ewe PP and three SR which included 180 medium prolificacy potential (MP – Suffolk-sired crossbred ewes) and 180 high prolificacy potential ewes (HP – Belclare-sired crossbred ewes) allocated to one of three (n = 60 ewes) SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) or high (HSR; 14 ewes per ha). Each treatment was managed in a 5-paddock rotational grazing system for the duration of the study. Medium prolificacy ewes were consistently heavier ($P<0.001$) compared to HP ewes, with HP ewes having a higher BCS at lambing and 6 weeks post-lambing (PL; $P<0.05$). Low SR ewes had a higher BW ($P<0.05$) and BCS ($P<0.05$) at mating, 6 weeks PL and weaning relative to MSR and HSR ewes which did not differ from each other. Lambs born to MP ewes were heavier at birth and weaning ($P<0.001$) and achieved a higher ADG from birth to weaning ($P<0.05$). Prolificacy potential had no effect on lifetime ADG or days to slaughter (DTS) with HP lambs yielding a higher carcass weight ($P<0.001$). Low SR and MSR lambs achieved higher ADG from birth to weaning ($P<0.001$) and weaning weight ($P<0.001$) relative to HSR lambs and did not differ from each other, while post-weaning and lifetime lamb ADG was highest at the LSR, intermediate at the MSR and lowest at the HSR ($P<0.001$). A ewe PP by SR interaction existed for DTS, with MP lambs at the LSR reaching slaughter weight earlier ($P<0.01$) relative to HP lambs, while at the MSR and HSR, MP and HP lambs did not differ from each other. High PP ewes produced a higher average born ($P<0.001$) and weaned litter size per ewe ($P<0.01$), with live weight weaned per hectare ($P<0.001$) increasing as ewe PP and SR increased. Lambing difficulty, ewe mother ability and lamb viability did not differ by ewe PP or SR. In conclusion, the lack of interaction between ewe PP and SR on many key performance measures in this study demonstrates the potential to increase the live weight of lamb weaned per hectare through the use of higher ewe PP and SR levels, with no effect of ewe PP on lifetime lamb performance even as SR increased, with reductions in lamb performance primarily occurring at the HSR.

4.2 Introduction

Sheep producers in temperate grazing regions predominantly operate grass-based lamb production systems due to the lower associated production costs of grazed grass to other alternative feed sources (Finneran et al., 2010). Maximizing flock productivity is crucial to the long-term sustainability of lamb production systems in these regions (Young et al., 2010). Often these systems do not operate to maximal efficiency, but could with increased use of available genetics, and improvements in flock nutrition and grazing management (Rattray, 1981).

Ewe prolificacy potential (PP) defined as the number of lambs born per ewe per year (Davis et al., 2006) and stocking rate (SR) defined as the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time (ewes per ha; Allen et al., 2011) are two main factors which influence flock productivity and subsequent output (Keady et al., 2009). Important measures of flock productivity include ewe BW, BCS (Kenyon et al., 2014), the number of lambs born and weaned per ewe, lamb growth rate and weaning weight (Cocks et al., 2002), days to slaughter and carcass weight (Keady et al., 2009). All these measures play a fundamental and integrated role in determining overall flock performance. The use of prolific ewe breeds and higher SR provides the opportunity to increase output (Keady et al., 2009), however, conversely both greater ewe PP and SR levels are often associated with reduced individual animal performance (Macdonald et al., 2008; Morris and Kenyon, 2004).

At present, there is a limited amount of information available comparing the combined effects of ewe PP, SR, and their interaction on flock performance in a grass-based lamb production system. Therefore, the objective of this study was to investigate the effect of ewe PP, SR and their interaction on ewe and lamb performance in a temperate grass-based lamb production system.

4.3 Materials and Methods

The study was carried out over three production years (October 2012 to December 2015) at the Sheep Research Demonstration Farm, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co Galway, Ireland (54° 80'N; 7°25'W). All procedures involving ewes and lambs in the study were conducted under license from the Irish Department of Health in accordance with the Cruelty to Animals Act 1876 and the European Communities Regulations, 1994.

4.3.1 Study Design and Animals

The study was a 2 x 3 factorial design, consisting of two differing ewe PP (Hanrahan, 1994) as dictated by sire breed and three SR. This included 180 medium prolificacy potential (MP – Suffolk-sired crossbred ewes) and 180 high prolificacy potential ewes (HP – Belclare-sired crossbred ewes), which were equally divided to one of three SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) or high (HSR: 14 ewes per ha), with each treatment consisting of 60 ewes. All ewes remained in their allocated treatment for the duration of the study unless they were culled or died, in which case a replacement ewe and her lambs, as appropriate, were added. The proportions of ewes by parity used each year in the study were 0.10 (parity one) and 0.90 (parity two) in 2013, 0.16 (parity one), 0.26 (parity two) and 0.59 (parity three) in 2014 and 0.20 (parity one), 0.12 (parity two), 0.20 (parity three) and 0.48 (parity four) in 2015.

A grassland area of 30.6 hectares was used for the duration of the study. This area was divided into five blocks based on location within the farm, soil type, and pasture age; each block was further divided into six paddocks, with one paddock per block randomly assigned to each treatment resulting in six independent grazing areas as shown in Figure 4.1. The LSR, MSR and HSR group had a total grazing area of 6.0, 5.0 and 4.3 hectares, respectively, with grazing areas managed in a 5-paddock rotational grazing system.

4.3.2 Flock Management

All ewes were mated to Charollais rams over a 6 week period in October and November each year. Ewes were housed on completion of the closing grazing rotation (HSR = early December, MSR = late December and LSR = mid-January). There were no differences in

herbage quality between the investigated treatments (Earle et al., 2016), with the nutrient composition of the grazed grass and silage offered to the ewes is shown in Table 4.1. Upon housing, based on AFRC (1993) ewes were offered a maintenance diet during mid-pregnancy of baled grass silage (mean 67.5 dry matter digestibility; DMD) ad libitum. In late pregnancy, ewes were offered higher quality baled grass silage (mean 72.7 DMD) ad libitum.

Ewes were pregnancy scanned 90 d after mating start date and concentrate supplementation was introduced to single and twin bearing ewes 6 weeks prior to predicted lambing start date (7 weeks for triplet bearing ewes), with concentrate supplementation levels based on silage quality and ewe energy requirements (AFRC, 1993) during late pregnancy. Ewe nutrient requirements varied by scanned litter size with single, twin and triplet bearing ewes receiving on average a total of 13, 20 and 27 kg of concentrates, respectively during late gestation. Across the three production years lambing commenced in early March. Post-lambing, ewes and lambs were turned out to pasture, with concentrate supplementation provided to ewes for a short time period in 2013 (weeks 3, 4 and 5 of lactation) and 2014 (weeks 3 and 4 of lactation) to meet ewe energy requirements during early lactation when pasture availability failed to meet energy requirements. Target pre-grazing sward heights were 7.0 to 9.0 cm (1200 to 1500 kg DM per ha) across all treatments. All treatments grazed to a targeted post-grazing sward height of 3.5 cm for the first grazing rotation and to post-grazing sward height targets of 4.5, 4.1, and 3.7 cm for the LSR, MSR and HSR groups for the remaining pre-weaning period. Post-weaning a leader-follower grazing system was operated, with LSR, MSR, and HSR groups grazing to targeted post-grazing sward heights of 5.5, 5.1, and 4.7 cm for lambs and 4.5, 4.1 and 3.7 cm for ewes, respectively. Lambs were weaned on average at 14 weeks of age and were drafted for slaughter to produce a target carcass weight of 20 kg. As lambs matured and kill out proportion reduced an increase in slaughter live weight was required as the season progressed as follows: 42, 43, 44, 45 and 46 kg in the months June, July, August, September and October, respectively. When grass supply dropped below 50 kg DM per ewe per hectare or lamb growth rate dropped below 100 g per day, lambs not slaughtered were removed from their grazing area and finished indoors on grass silage ad libitum and concentrate supplementation. This was done to maintain adequate grass supplies for ewes during mating and early pregnancy.

4.3.3 Animal Measurements

Ewe BCS measured on a one to five point scale at 0.25 increments (one = emaciated, five = over fat; Jefferies, 1961) and BW were recorded at mating, pregnancy scanning, lambing, 6 weeks post-lambing (PL), and weaning. All lambs were tagged, weighed and matched to their dams within 24 hours of birth. Lambing difficulty was assessed on a scale of one to four (one = no assistance, two = little assistance, three = manual delivery and four = difficult or severe assistance). Ewe mother ability was measured on a scale of one to three (one = always follows lambs, two = stands well back from lambs and three = leaves lambs). Lamb viability was measured on a two-point scale (one = required no assistance to suckle and two = required assistance to suckle) (Annett et al., 2012). Birth date, litter size, and lamb sex were also recorded. Lamb mortality (defined as alive or dead) within the first 24 hours of life, post-birth (from 24 hours post-birth to slaughter), and total (from birth to slaughter) was recorded.

Lambs were weighed at 2 week intervals from 6 weeks of age to slaughter and ADG calculated accordingly; Pre-weaning ADG = ((live weight (kg) - birth weight (kg)) divided by age at date weighed). Post-weaning ADG = ((drafting live weight (kg) - weaning live weight (kg)) divided by No. days post-weaning). The number of days required to reach slaughter (DTS) was calculated as the number of days from birth to slaughter. Lifetime ADG = ((drafting live weight (kg) - birth weight (kg) divided by DTS.

Carcass conformation was scored using the EUROP grid system (E = excellent and P = poor) and external fat score was scored using a one to five scoring system in order of increasing fatness (1 = low fat cover; 5 = high fat cover; Hickey et al., 2007). Dressing proportion was calculated as cold carcass weight (kg) divided by pre-slaughter live weight (kg). Lamb faecal egg counts for *Nematodirus*, *Trichostrongylus*, and *Strongylus* were monitored within each treatment group (20 random samples) every 2 weeks from May to October using the FECPAK technique (Fecpak International Ltd., New Zealand).

4.3.4 Statistical Analyses

The effect of ewe PP and SR on ewe BW, proportion of change in BW, BCS, change in BCS, the number of lambs born and weaned per ewe, lambing difficulty, ewe mother ability, litter live weight weaned per ewe, lamb birth weight, weaning weight, ADG, drafting weight, DTS, and carcass traits were analysed using a linear mixed model in PROC HP MIXED (SAS,

2012) with ewe included as a random effect and ewe PP, SR, parity, year, and the interaction between ewe PP and SR included as fixed effects. Deviation in age from the treatment was included as a fixed effect for analysis of lamb ADG. The effect of ewe PP and SR on litter live weight weaned per hectare and lamb faecal egg counts were analysed using a linear mixed model in PROC HP MIXED (SAS, 2012) with ewe PP, SR, year, and the interaction between ewe PP and SR included as fixed effects. For the binary traits lamb mortality (defined as alive or dead) within the first 24 hours of life, post-birth (from 24 hours post-birth to slaughter), total mortality (birth to slaughter), ewe replacement rate, and lamb viability, the log of the odds were modelled using logistic regression in PROC GENMOD (SAS, 2012) with ewe PP, SR, parity, year, and the interaction between ewe PP and SR included as fixed effects. Odds ratios were calculated as the exponent of the model solutions. For all traits, where an interaction existed between ewe PP and SR, orthogonal contrasts were used to compare differences between ewe PP within SR.

4.4 Results

4.4.1 Ewe Performance

The effect of ewe PP and SR on ewe BW and the proportion of change in BW, throughout the production year are shown in Table 4.2. No ewe PP by SR interactions were observed for ewe BW or the proportion of change in BW. At all measured time-points MP ewes were significantly heavier ($P < 0.001$), with an average BW difference of 4.8 kg recorded between the two ewe PP.

Stocking rate significantly affected ewe BW, with LSR ewes achieving a higher BW at all measured time-points ($P < 0.05$) compared to MSR and HSR ewes which did not differ from each other, with the exception of pregnancy scanning where LSR and HSR ewes did not differ from each other.

From 6 weeks PL to weaning, HP ewes lost a higher proportion of BW ($P < 0.01$) compared to MP ewes but from weaning to mating regained a higher proportion of BW ($P < 0.001$). From 6 weeks PL to weaning, LSR ewes lost a lower proportion of BW ($P < 0.01$) compared to MSR and HSR ewes which did not differ from each other. From weaning to mating, LSR ewes also

had a higher proportion of BW gain ($P<0.05$) compared to MSR and HSR ewes, which did not differ from each other (Table 4.2).

With the exception of lambing and 6 weeks PL, ewe BCS did not differ by ewe PP (Table 4.3). At lambing and 6 weeks PL, HP ewes achieved a higher BCS ($+0.06$; $P<0.05$) compared to MP ewes. From pregnancy scanning to 6 weeks PL, MP ewes lost a higher level of body condition compared to HP ewes ($P<0.05$) but subsequently regained a higher level of body condition ($P<0.05$) from 6 weeks PL to weaning.

Low SR ewes had a higher BCS at mating (Table 4.3; $P<0.001$) compared to MSR and HSR ewes which did not differ from each other. At 6 weeks PL and weaning, LSR ewes had a higher BCS ($P<0.001$) compared to MSR and HSR ewes which did not differ from each other. From mating to pregnancy scanning LSR and MSR ewes lost body condition while HSR ewes gained a small level of body condition, with all three SR differing from each other ($P<0.001$) although absolute changes in BCS were small. Low SR ewes experienced a lower loss of body condition ($P<0.001$) from pregnancy scanning to 6 weeks PL and regained more body condition ($P<0.05$) from 6 weeks PL to weaning compared to MSR and HSR ewes which did not significantly differ from each other during these time periods.

Lambing difficulty, ewe mother ability, and lamb viability score did not differ by ewe PP or SR (Table 4.4). The average number of lambs born and weaned per ewe and live weight weaned per ewe and per hectare are shown in Table 4.5. High prolificacy potential ewes produced a higher average born ($+0.20$ lambs per ewe; $P<0.001$) and weaned litter size ($+0.18$ lambs per ewe; $P<0.01$) compared to MP ewes. The proportion of single and multiple litters was 0.22 and 0.78 in the MP and 0.15 and 0.85 in the HP groups. Prolificacy potential and SR had no effect on the litter live weight of lamb born or weaned per ewe. High prolificacy ewes weaned 45 kg per hectare more lamb compared to MP ewes ($P<0.001$). Live weight weaned on per hectare increased as SR increased ($P<0.05$). Ewe replacement rate did not differ by ewe PP ($P>0.05$), however, high SR ewes had increased odds of 1.56 (1.05 – 2.33) and 1.71 (1.15 – 2.54; $P<0.05$) of being replaced compared with LSR and MSR ewes, which did not differ.

4.4.2. Lamb Performance

Ewe PP significantly affected lamb birth weight with MP ewes producing heavier lambs at birth compared to HP ewes (Table 4.6; +0.5 kg; $P<0.001$). Pre-weaning, MP lambs achieved a higher ADG from birth to 6 weeks of age ($P<0.05$) and from birth to weaning ($P<0.05$) compared to HP lambs, this in turn resulted in MP lambs achieving a higher weaning weight (+1.0 kg; $P<0.001$) relative to HP lambs. Post-weaning, HP lambs achieved a higher ADG ($P<0.01$) compared to MP lambs. Lifetime lamb ADG from birth to slaughter, lamb drafting weight, DTS or carcass conformation did not differ by ewe PP. Lambs born to HP ewes achieved a higher dressing proportion ($P<0.001$), heavier carcass weight (Table 7; +0.4 kg; $P<0.001$), and carcass fat score ($P<0.001$) relative to MP lambs

High SR lambs had a lower ADG from birth to 6 weeks of age (Table 4.6; $P<0.05$) compared to LSR and MSR lambs which did not differ from each other. Low SR and MSR lambs achieved a higher ADG from birth to weaning ($P<0.001$) and subsequent weaning weight ($P<0.001$) compared to HSR lambs and did not differ from each other. Post-weaning ($P<0.001$) and lifetime ADG ($P<0.001$) was highest at the LSR, intermediate at the MSR, and lowest at the HSR (Table 4.7). Stocking rate had no effect on lamb drafting weight, dressing proportion, or carcass fat. Low SR lambs achieved a higher carcass weight and conformation score ($P<0.05$) compared to HSR lambs, with MSR lambs not differing from either the LSR or HSR lambs. With the exception of lamb mortality post-birth (from 24 hours post-birth to slaughter), lamb mortality (lamb mortality within the first 24 hours of life and total) did not differ by ewe PP or SR. High SR lambs were 1.61 times more likely (0.75 – 1.94; $P<0.05$) to die post-birth relative to MSR lambs while LSR lambs did not differ from either the MSR or HSR lambs. Lamb faecal egg counts for *Nematodirus*, *Trichostrongylus*, *Strongyloides*, and total faecal egg count (*Nematodirus*, *Trichostrongylus*, *Strongyloides* counts combined) did not differ by ewe PP or SR ($P>0.05$).

A ewe PP by SR interaction was observed for lamb ADG from 6 to 14 weeks of age where relative to HP lambs, MP lambs at the HSR achieved a higher ADG (+32 g per day; SE = 6.0; $P<0.001$) while at the LSR, HP lambs achieved a higher ADG, with MP and HP lambs at the MSR achieving a similar level of ADG and did not differ. A ewe PP by SR interaction was observed for DTS with MP lambs at the LSR reaching slaughter faster (-17 days; SE = 6.1; $P<0.01$) relative to HP lambs, with MP and HP requiring a similar period of time to reach

slaughter at the MSR and HSR. The average proportion of lambs (mean of three production years) requiring supplementation to finish was 0.15 and 0.14 for the MP and HP groups ($P>0.05$) and 0.09, 0.14, and 0.20 for the LSR, MSR and HSR group ($P<0.05$), respectively.

4.5 Discussion

Numerous studies have demonstrated higher output to be achievable through the use of prolific ewe genotypes (Dawson and Carson, 2002) and increasing SR (Keady et al., 2009) across lamb production systems. The use of prolific ewe genotypes and higher SR to increase output in grass-based lamb production systems often presents a challenge to producers due to the higher number of animals needing to be supported and finished on pasture. Animal performance in grazing ruminant production systems is primarily influenced by animal, nutritional, and environmental factors (Geenty, 1983; Scaramuzzi and Martin, 2008) and despite previous research on ewe PP and SR, there is limited information available on the interaction between ewe PP and SR, which are two of the most important economic factors influencing output in temperate grass-based lamb production systems. The ewe genotypes selected and used in this study have previously been demonstrated to have differences in prolificacy by Hanrahan et al. (1994), with numerous genetic studies on the ovine ovary identifying the Belclare breed to be a carrier of the oocyte-derived growth differentiation factor 9 (GDF9) and bone morphogenetic protein 15 (BMP15) mutations which are associated with increased ovine prolificacy (Davis et al., 2006; Hanrahan et al., 2004). This study also allows for greater feeding and management control relative to large population studies, where it is difficult to account for the influences of on-farm decisions. The limitations of treatment replication in this systems study were overcome by repeating the study over three consecutive years, with no treatment by year interactions observed. This data set provides a unique opportunity to accurately investigate the effect of ewe PP, SR, and their interaction on ewe and lamb performance in a temperate grass-based lamb production system.

The BW and BCS profile of the grazing ewe is a useful indicator of her nutritional and physiological status (Adams et al., 2007), with dynamic changes of BW and BCS reflecting differences between energy requirements and intakes of the ewe. Many studies have reported ewe BW and BCS to be positively associated with key production traits such as ovulation rate (Rhind et al., 1984), number of lambs born per ewe, lamb birth weight and lamb survival and growth (Kenyon et al., 2014). Ewes used in this study were assembled from a study by Earle

et al. (2016) in which ewes were blocked within each ewe PP level post pregnancy scanning based on BW, BCS and pregnancy scanned litter size, before being randomly assigned to one of the three SR used. Therefore any effects observed in this study are results of the ewe PP and SR imposed.

The mobilization of ewe body reserves during late pregnancy and lactation (McGovern et al., 2015) are to be expected as the ewe attempts to consume enough energy to support her own maintenance requirements, fetal growth and development (Robinson et al., 1977), commence milk synthesis and support the growth of her offspring to weaning (Robinson et al., 1983). During late pregnancy encroachment of the uterus on the rumen reduces the intake capacity of the ewe, with full feed intake capacity not returning until approximately 6 weeks PL (Forbes, 1968). Coinciding with this reduction in rumen capacity and feed intake is a significant increase in energy requirement particularly during early lactation, resulting in the ewe mobilising body reserves to meet her energy requirements (AFRC 1993; Robinson et al., 1983). Morris and Kenyon, (2004) observed no effect of litter size on ewe BW and BCS during pregnancy or lactation. A study by Dawson and Carson, (2002) observed prolific crossbred ewe genotypes rearing 20% more lambs per ewe to experience a higher loss in BW and BCS during the last 6 weeks of pregnancy and the first 6 weeks of lactation relative to lower prolific crossbred genotypes. This increased mobilization of body reserves is possibly a combined effect of the reduced feed intake capacity during this time period and a result of suckling a higher number of lambs, with an increased energy demand of early lactation (Vulich et al., 1991). Many studies have observed twin bearing ewes to have a lower BCS relative to singles at the end of pregnancy and during lactation (Corner-Thomas et al., 2013; Kenyon et al., 2009). In contrast the higher BCS of the HP ewes at lambing and in early lactation in the present study would indicate that the HP ewes had a greater potential to maintain their body condition relative to the MP ewes despite rearing a higher litter size (Campion et al., 2016). The higher loss of body condition experienced by the MP ewes from pregnancy scanning to 6 weeks PL would indicate that they were utilising more of their body reserves to meet energy requirements in late pregnancy and early lactation. The higher mature BW and increased energy requirement for maintenance is a possible contributor to this increase in loss in body condition score (AFRC, 1993). The biological difference in BCS change between the two ewe PP, however, is small and this combined with the lack of difference observed in litter live weight born per ewe would suggest no negative impact on ewe productivity. Provided the ewe's nutritional needs are met during this time period the ewe

will typically gain body reserves in late lactation once the high energy demand of peak lactation has passed, with excess energy stored in the form of muscle and fat reserves (Jagusch and Coop, 1971). This was observed in the present study where all ewes gained body condition from 6 weeks PL to weaning. Ewe BCS recorded were within the recommended production targets (Defra, 2000) with no adverse effect of ewe PP on the ability of the ewe to adequately restore losses of body reserves sustained during pregnancy and lactation before the next breeding season.

The differences in dynamic changes in BW in this study provide a more accurate description of the effect of ewe PP and SR on ewe performance, due to the natural variation in the mature BW between the MP (Suffolk-sired crossbred) and HP (Belclare-sired crossbred) ewes (Meat and Livestock Commission, 1988). The lack of difference in the proportion of BW change in response to ewe PP up to weaning suggests MP and HP ewes had a similar response to changes in energy demand and supply, with the dry period from weaning to mating demonstrating the capacity of the HP ewes to recover double the proportion of BW in a grass-based system compared to MP ewes. In this study both MP and HP received the same daily herbage feed allowance. Therefore this gain in body reserves is a probable result of their lower maintenance requirement (AFRC, 1993) which allowed them to restore body reserves mobilised during late pregnancy and lactation more efficiently from pasture once their lambs were weaned.

Previous authors have reported negative effects of increasing SR on individual animal performance (Kemp et al., 2013; McCarthy et al., 2012a). Interestingly in the current study ewe BW and BCS decreased when SR increased from 10 to 12 ewes per hectare and 14 ewes per hectare but did not differ between 12 and 14 ewes per hectare. The lack of difference in BW and BCS between the MSR and HSR ewes at mating, 6 week PL and weaning would suggest that potentially the LSR ewes had a higher feed availability than required throughout the production year which was reflected in their higher BW and BCS (Corner-Thomas et al., 2015). The management of the treatments in this study aimed to optimise herbage utilisation (Earle et al., 2016) and meet ewe nutritional requirements at all times. If all treatments were housed for at the same time and fed equal amounts of feed, then the true effects of such systems on ewe performance would not have been truly demonstrated and further losses in ewe BW and BCS may have occurred when SR increased from 12 to 14 ewes per hectare.

Lambing difficulty, ewe mother ability and lamb viability are major contributing factors to flock productivity and labour requirements at lambing (Fisher, 2003), with increased incidences of lambing difficulty and lamb mortality often associated with higher litter sizes and heavier lamb birth weights (Everett–Hincks et al., 2005; Maxa et al., 2009). The lack of effect of ewe PP or SR on these parameters in the present study can be attributed to ewes in this study achieving recommended BCS targets (Defra, 2000), the low lambing difficulty, and good mother ability scores and birth weights recorded.

Lamb birth weight is strongly correlated with the mature body weight of the ewe (Donald and Russell, 1970) and this combined with the lower born litter size of the MP ewes is a plausible explanation for the heavier birth weight and weaning weight of the MP lambs. Lamb performance during the early pre-weaning period is primarily governed by the milk yield potential of the ewe (Forbes, 1968; McGovern et al., 2015). The higher ADG of the MP lambs is a combined effect of their higher birth weight and reduced competition for milk supply during the first 6 weeks of life. Despite MP lambs achieving a higher pre-weaning ADG, the differences in growth between the two ewe PPs are biologically small, with no adverse effect of ewe PP on lifetime lamb ADG or the time required to reach slaughter in the present study.

Milk intake of the lamb decreases after the peak milk yield potential of the ewe has been reached typically in weeks three and five of lactation for single and twin rearing ewes (Cardellino and Benson, 2002) with lambs thereafter increasing their consumption of solid feed in order to meet the energy requirements for maintenance and growth (Muir et al., 2000). Grass availability and quality therefore are of great influence on lamb growth rate in the late pre-weaning period (Coop et al., 1972; Peart, 1982). The ewe PP by SR interaction for lamb ADG from 6 to 14 weeks of age can be attributed to the lower grazing competition experienced by MP at the HSR compared to the HP lambs, resulting in the higher ADG achieved.

The similar ADG from birth to weaning and weaning weight achieved by the LSR and MSR lambs in the present study, can be explained by the higher loss in body reserves experienced by the MSR ewes relative to LSR ewes which somewhat acted as a buffer between reduced feed supply and lamb growth rate during lactation (Coop et al., 1972). The lower pre-weaning performance by HSR lambs combined with reduced ewe BW and BCS would suggest that

grazing competition for available pasture was much greater in the HSR system compared to the LSR (Creighton and Kelly, 2014; Earle et al., 2016).

Post-weaning lamb growth rate is often lower than desired particularly when grazing perennial ryegrass swards (Golding et al., 2011). Post-weaning ADG recorded in this study was lower than that reported by Fraser et al. (2004) and similar to that achieved by Keady et al. (2009) grazing perennial ryegrass swards. The ADG post-weaning experienced by the HP lambs would indicate their ability to compensate for reductions in growth rate that occurred from birth to 6 weeks of age, which is a possible result of the earlier adaption of their diet to pasture (Peart, 1982). The decrease in post-weaning and lifetime lamb ADG as SR increased is a potential effect of the lower target post-grazing sward residuals imposed at the MSR and HSR and seasonal reduction in herbage quality during the main grazing season (McCarthy et al., 2012b). The ewe PP by SR interaction observed for DTS saw MP lambs at the LSR to reach slaughter at a younger age can be attributed to their higher pre-weaning performance relative to HP lambs and also to the increased opportunity of diet selection afforded to lambs at the LSR, with MP and HP lambs requiring a similar period of time to reach slaughter at the MSR and HSR.

The total body weight of the lamb at drafting consists of carcass and non-carcass components, with the relative proportion of bone, muscle (lean) and fat differing between breeds (Speedy, 1980). The higher kill out proportion and fat score recorded for HP lambs resulted in a 0.4 kg higher carcass weight which corroborates previous studies (Hanrahan, 1999). This is an important finding from this study as lamb producers are primarily paid on lamb carcass weight. Sheep breeds of lower mature body weight typically have a higher fat score relative to breeds of a greater mature body weight when carcass composition is compared at the same carcass weight (Kirton, 1982). The higher carcass fat score of the HP lambs is a probable result of their lower mature body weight relative to the MP lambs in this study.

In conclusion, ewe PP had no significant effect on lifetime lamb performance and many other key productivity indicators. The lack of interaction between ewe PP and SR on ewe performance and lifetime lamb performance in this study illustrates great potential to increase ewe PP in grass based lamb production system. The use of higher SR in this study demonstrates the potential to increase the live weight of lamb weaned per ha in a grass-based lamb production, with the 10 and 12 ewes per hectare systems achieving similar levels of

performance for pre-weaning ADG and DTS. The current findings suggest some potential limitations to increasing SR above 12 ewes per hectare in a grass-based lamb production system due to lower individual lifetime lamb ADG. Producers should therefore be careful not to increase to SR levels that cannot be supported by their farm which will be influenced by its grass growing potential when making decisions to increase SR levels.

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3371 **Table 4.1** Nutrient composition of grazed grass and silage offered to ewes throughout the production year¹ (g per kg DM unless stated
3372 otherwise)

Parameter	Pre-weaning grazed grass	Post-weaning grazed grass	Mid-pregnancy silage ²	Late-pregnancy silage ³
Dry matter	-	-	228	261
Organic matter	901	895	-	-
Ash	99	104	79	70
Crude protein	211	184	114	123
Neutral detergent fibre	437	485	524	468
Acid detergent fibre	221	258	-	-
Organic matter digestibility	751	720	-	-
Dry matter digestibility	-	-	67.5	72.7
ME, MJ ME per kg DM	11.1	10.4	9.6	10.5

3373 ¹Herbage quality did not differ by PP and SR in this study.

3374 ²Silage fed to ewes from housing to 8 weeks prior to predicted lambing date.

3375 ³Silage fed to ewes in last 8 weeks of pregnancy.

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3377 **Table 4.2** The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on ewe BW and the proportion of BW change throughout the
3378 production year (Least Square Means \pm SEM)

Parameter	PP			SR			<i>P-value</i>			
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
BW, kg										
Mating	79.5	76.6	0.59	80.1 ^a	77.6 ^b	76.5 ^b	0.71	***	***	NS
Pregnancy scanning	83.3	77.3	0.58	81.9 ^a	79.1 ^b	80.0 ^{ab}	0.72	***	**	NS
6 weeks PL ³	81.3	76.8	0.63	80.6 ^a	78.1 ^b	78.4 ^b	0.76	***	*	NS
Weaning	77.4	71.7	0.61	76.6 ^a	73.6 ^b	73.4 ^b	0.73	***	**	NS
Proportion of change in BW										
Mating to pregnancy scanning	0.07	0.07	0.003	0.07	0.07	0.08	0.004	NS	NS	NS
6 weeks PL ³ to weaning	-0.05	-0.06	0.004	-0.04 ^a	-0.06 ^b	-0.06 ^b	0.004	*	*	NS
Weaning to mating	0.03	0.06	0.003	0.05 ^a	0.04 ^b	0.04 ^b	0.004	***	**	NS

3379 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

3380 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

3381 ³6 weeks PL = 6 weeks post-lambing.

3382 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

3383 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 4.3 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on ewe body condition score and body condition score change throughout the production year (Least Square Means \pm SEM)

Parameter	PP			SR			<i>P-value</i>			
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Body condition score, 1-5 index scale										
Mating	3.29	3.34	0.025	3.45 ^a	3.26 ^b	3.23 ^b	0.031	NS	***	NS
Pregnancy scanning	3.33	3.32	0.018	3.31 ^a	3.29 ^a	3.36 ^b	0.021	NS	NS	NS
Lambing	3.17	3.23	0.021	3.25 ^a	3.19 ^{ab}	3.15 ^b	0.026	*	*	NS
6 weeks PL ⁴	2.95	3.01	0.022	3.06 ^a	2.94 ^b	2.95 ^b	0.026	*	**	NS
Weaning	3.07	3.07	0.028	3.19 ^a	3.01 ^b	3.01 ^b	0.034	NS	***	NS
Body condition score change (1-5 index scale)										
Mating to pregnancy scanning	-0.03	-0.04	0.016	-0.12 ^a	-0.02 ^b	0.04 ^c	0.016	NS	***	NS
Pregnancy scanning to lambing	-0.15	-0.10	0.021	-0.11 ^a	-0.09 ^a	-0.18 ^b	0.021	NS	*	NS
Lambing to 6 weeks PL ⁴	-0.23	-0.24	0.022	-0.20	-0.26	-0.24	0.022	NS	NS	NS
Pregnancy scanning to 6 weeks PL ⁴	-0.37	-0.31	0.020	-0.25 ^a	-0.38 ^b	-0.39 ^b	0.024	*	***	NS
6 weeks PL ⁴ to weaning	0.12	0.05	0.019	0.13 ^a	0.07 ^b	0.06 ^b	0.019	*	*	NS
Weaning to mating	0.22	0.23	0.021	0.23	0.25	0.20	0.021	NS	NS	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

⁴6 weeks PL = 6 weeks post-lambing.

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 4.4 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lambing difficulty, ewe mother ability and lamb viability score (Least Square Means \pm SEM)

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Lambing difficulty [†]	1.54	1.43	0.052	1.55	1.45	1.47	0.063	NS	NS	NS
Ewe mother ability [‡]	1.29	1.21	0.034	1.28	1.21	1.26	0.041	NS	NS	NS
Lamb viability [▲]	1.07	1.06	0.015	1.05	1.08	1.05	0.018	NS	NS	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

[†]Lambing difficulty (one = no assistance, two = little assistance, three = manual delivery and four = difficult or severe assistance).

[‡]Ewe mother ability (one = always follows lambs, two = stands well back from lambs and three = leaves lambs).

[▲]Lamb viability (one = required no assistance to suckle and two = required assistance to suckle).

3402 **Table 4.5** The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lamb output (Least Square Means \pm SEM)

Parameter	PP ¹			SR ²				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
No. of lambs born per ewe	1.87	2.07	0.031	2.00	1.92	1.99	0.038	***	NS	NS
No. of lambs weaned per ewe	1.50	1.68	0.031	1.63	1.57	1.56	0.038	**	NS	NS
Litter birth weight per ewe, kg	8.43	8.32	0.116	8.48	8.34	8.31	0.139	NS	NS	NS
Live weight weaned per ewe, kg	47.3	51.0	0.28	52.0 ^a	49.0 ^b	46.0 ^c	0.34	***	***	NS
Live weight weaned per ha, kg	565	611	3.9	520 ^a	591 ^b	646 ^c	4.18	***	***	NS

3403 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

3404 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

3405 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

3406 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

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3408 **Table 4.6** The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lamb birth weight , ADG³ and weaning body weight (Least
3409 Square Means \pm SEM)

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Birth weight, kg	5.1	4.6	0.05	4.9	4.9	4.8	0.06	***	NS	NS
ADG, g per day										
Birth to 6 weeks	287	278	2.9	287 ^a	287 ^a	275 ^b	3.5	*	*	NS
6 to 14 weeks	245	240	2.0	256 ^a	248 ^b	223 ^c	2.5	NS	***	***
Birth to weaning	261	255	2.0	268 ^a	263 ^a	243 ^b	2.4	*	***	NS
Weaning weight, kg	31.5	30.5	0.22	32.0 ^a	31.5 ^a	29.6 ^b	0.27	***	***	NS

3410 ¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

3411 ²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

3412 ³ADG = average daily gain (g per day).

3413 ^{a,b,c} Within rows, means with differing superscripts significantly differ.

3414 *P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

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Table 4.7 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on post-weaning and lifetime lamb ADG³, days to slaughter and carcass traits (Least Square Means \pm SEM)

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Post-weaning ADG	158	167	2.6	176 ^a	161 ^b	150 ^c	3.2	**	***	NS
Lifetime ADG	218	216	2.4	231 ^a	219 ^b	200 ^c	2.9	NS	***	NS
Drafting weight, kg	45.1	45.1	0.06	45.2	45.1	45.1	0.07	NS	NS	NS
Days to slaughter	215	215	3.0	203 ^a	213 ^a	230 ^b	3.3	NS	***	**
Carcass weight, kg	19.6	20.0	0.06	19.9 ^a	19.8 ^{ab}	19.7 ^b	0.07	***	*	NS
Carcass conformation	3.0	3.0	0.02	3.1 ^a	3.0 ^{ab}	3.0 ^b	0.02	NS	*	NS
Carcass fat	2.8	2.9	0.02	2.8	2.8	2.8	0.03	***	NS	NS
Dressing proportion	0.43	0.44	0.001	0.44	0.44	0.44	0.005	***	NS	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³ADG = average daily gain (g per day).

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

			3	2	1	3	5	6
			4	1	2	5	4	5
3	2	4	5	6	6	4	3	1
5	1	6			1	6	5	
					3	4	2	

Figure 4.1 Arrangement of grazing areas for each treatment[‡]

[‡]1 = LSR HP (low stocking rate, high prolificacy), 2 = MSR HP (medium stocking rate, high prolificacy), 3 = HSR HP (high stocking rate, high prolificacy), 4 = LSR MP (low stocking rate, medium prolificacy), 5 = MSR MP (medium stocking rate, medium prolificacy), 6 = HSR MP (high stocking rate, medium prolificacy). ----- = roadway access to paddocks.

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5. Chapter five

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3441 **Evaluation of the effects of ewe prolificacy potential and stocking**

3442 **rate on herbage production, utilisation, quality, and sward**

3443 **morphology in a temperate grazing system**

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Submitted to Grass and Forage (First Revision)

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E. Earle, N. McHugh, T.M Boland, P. Creighton

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5.1 Abstract

This study investigated the effect of ewe prolificacy potential (PP; predicted number of lambs born per ewe per year), stocking rate (SR; ewes per ha), and their interaction on herbage dry matter (DM) production, utilisation, quality, and sward morphology within a temperate grass-based lamb production system. The study had a 2 x 3 factorial design, consisting of two ewe PP (180 medium prolificacy potential (MP – Suffolk crossbred) and 180 high prolificacy potential ewes (HP – Belclare crossbred)) and three SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha), and high (HSR; 14 ewes per ha). Each treatment was managed in a rotational grazing system, with LSR, MSR, and HSR treatments grazing to target post-grazing sward heights (PGSH) of 4.55, 4.15, and 3.75 cm, respectively. Herbage DM production (> target PGSH) and utilisation was highest at the HSR, intermediate at the MSR and lowest at the LSR ($P<0.001$). Ewe PP had no effect on herbage DM production, utilisation, quality, or sward morphology ($P>0.05$). The proportion of leaf in the sward (> target PGSH) was 4% higher in MSR and HSR compared to LSR ($P<0.05$). In conclusion, findings demonstrate the potential to support increased ewe PP and SR within a temperate grass-based lamb production system.

5.2 Introduction

The supply of high quality pasture is crucial for maximizing animal performance in pasture-based ruminant production systems, with imposed grazing management decisions significantly influencing sward productivity and quality (Francis and Smetham, 1985; Webby and Sheath, 2000). Grass, either grazed or conserved, can supply up to 95% of the energy requirements of sheep (Davies and Penning, 1996), providing producers in temperate grazing regions an ideal opportunity to maximise output from grass through increased herbage dry matter (DM) production and utilization (Keady et al., 2009; Shalloo et al., 2004). Grazing systems that can optimise the proportion of grazed grass utilised (Dillon et al., 2005) have the potential to operate more profitably due to the lower associated cost of production of grazed grass relative to alternative feed sources (Finneran et al., 2010).

The ewe prolificacy potential (PP; predicted number of lambs born per ewe per year; Davis et al., 2006) of a flock is a major contributing factor to feed requirements and grazing intensity throughout the grazing season in temperate grass-based lamb production systems (Keady et al., 2009). Increases in the number of lambs reared per ewe are often associated with increased feed requirements of the ewe during lactation (AFRC, 1993). However, research by Morris and Kenyon, (2004) and Gibb and Treacher, (1982) both concluded that litter size reared per ewe has no effect on herbage intake per ewe. The earlier adaptation of the growing lamb to herbage/solid feed as litter size increases due to reductions in milk intake is widely acknowledged (Galvani et al., 2014). This would suggest grazing competition and intensity to be greater in more prolific flocks as a result of the greater number of animals' competing for available resources within the grazing area.

Stocking rate (SR; ewes per ha) is defined as the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time (Allen et al., 2011). Herbage production (kg DM per ha per year) globally varies considerably depending on climate, location, season, soil fertility, and stage of plant growth. Management factors including SR, timing of fertiliser application, and pre- and post-grazing herbage mass targets are considered key determinants of herbage availability per animal, with SR levels imposed by far the most influential management factor determining output within grass-based lamb production systems (Baudracco et al., 2010; Keady et al., 2009). Variable effects of increasing SR on sward productivity have been reported within the literature with some studies

indicating increased SR levels to positively improve herbage DM production, utilization (Macdonald et al., 2008; McCarthy et al., 2012), quality, and sward morphology (Francis and Smetham 1985; Lee et al., 2007). However others have shown that increased SR has a negative impact on pasture growth, availability, and individual animal performance (Morley, 1981).

Within the grazing system both animal and pasture production is greatly influenced by the production potential of the grazing animal and SR level imposed (Earle et al., 2016a; McCarthy et al., 2012). Understanding the effects of ewe PP and SR on herbage DM production, utilization and sward characteristics is fundamental to the development and optimization of temperate grass-based lamb production systems. Currently there is limited information relating to the effect of ewe PP and SR on sward productivity in a temperate grazing system. Therefore, the objective of the present study was to evaluate the effect of ewe PP, SR, and their interaction on herbage DM production, utilization, quality, and sward morphology.

5.3 Material and methods

The study was undertaken at the Sheep Research Demonstration Farm, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co Galway, Ireland (54° 80'N; 7°25'W) from October 2012 to December 2015 (three production years). The study site had a free-draining brown earth soil over limestone bedrock and a fine loamy texture. The on site swards predominantly consisted of perennial ryegrass (*Lolium perenne* L.) species, with low levels of white clover (*Trifolium repens*), *Agrostis* and *Poa* species also present and had been reseeded over the previous one to six years.

5.3.1 Study design, treatments and flock management

The study had a 2 x 3 factorial design, consisting of two ewe PP and three SR. This included 180 medium prolificacy potential (MP – Suffolk crossbred ewes) and 180 high prolificacy potential ewes (HP – Belclare crossbred ewes), which were equally divided to one of three SR's: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) or high (HSR: 14 ewes per ha), with each treatment consisting of 60 ewes. A grazing area of 30.6 hectares was used for the study and consisted of five grazing blocks. Within each block, paddocks were randomly

assigned based on location within the farm, soil type, and pasture age to each treatment, establishing six independent grazing areas. The total grazing area for the LSR, MSR, and HSR groups was 6.0, 5.0, and 4.3 hectares, respectively, with grazing areas managed in a five paddock rotational grazing system.

5.3.2 Flock and grazing management

Ewes commenced lambing in early March each year. Post-lambing, ewes and lambs were turned out to pasture. A more detailed description of animal management and measurements taken over the three year study period are described by Earle et al. (2017). Inorganic fertiliser application rates were applied at a rate of 13 kg Nitrogen (N) per ewe per year, 20 kg phosphorus (P), and 45 kg potassium (K) per hectare per year, respectively. Nitrogen was applied after grazing rotations two to six at an average rate of 2.6 kg N per ewe per application, with P and K applied in two applications, the first in early summer and second in the autumn period. Lime was applied at a rate of 2500 kg per hectare on 20% of each grazing area based on soil fertility analysis undertaken in autumn 2014. Herbage availability (herbage mass; kg DM per ha) was estimated weekly using the rising plate meter method (O'Donovan et al., 2002) and recorded on Pasturebase, (a grass budgeting management tool; Pasturebase Ireland, National Grassland Database, Oak park, Co, Carlow, Ireland) with grazing management decisions based on grass budget information and target post-grazing sward heights (PGSH) being reached. Target pre-grazing sward heights were 7.0 to 9.0 cm (1200 to 1500 kg DM per ha) across all treatments. All treatments grazed to a targeted PGSH of 3.5 cm for the first grazing rotation and to PGSH targets of 4.55, 4.15, and 3.75 cm for the LSR, MSR and HSR, respectively for the remaining pre-weaning period. Post-weaning a first to last grazing system (lambs grazing ahead of ewes in a leader follower grazing system) was operated, with LSR, MSR, and HSR groups grazing to a target PGSH of 5.55, 5.15, and 4.75 cm for lambs and 4.55, 4.15, and 3.75 cm for ewes, respectively. Paddocks were split using temporary electric fencing from the second grazing rotation once herbage availability above target PGSH exceeded four days. Twenty percent of each grazing area was closed for silage in mid to late April, once grass supply exceeded flock demand (minimum farm cover 50 kg DM per ewe per hectare). In order to maintain sward quality, surplus grass was removed as baled silage or paddocks were mechanical topped to 4.0 cm at least once during the main grazing season. The final grazing rotation commenced in October each year with a targeted PGSH of 4.0 cm and total grazing area of 20% closed by the end of October and 40% by mid-

November for all treatments. All treatments were housed on completion of the closing grazing rotation (HSR = early December, MSR = late December, and LSR = mid-January). Upon housing, based on AFRC (1993) recommendations/guidelines, ewes were offered a maintenance diet during mid-pregnancy of baled grass silage (mean 67.5, dry matter digestibility; DMD) ad libitum. In late pregnancy, ewes were offered higher quality baled grass silage (mean 72.7 DMD) ad libitum plus concentrate supplementation.

5.3.3 Grassland measurements

Pre-grazing herbage mass (> 3.5 cm) was determined prior to grazing for each paddock by harvesting a strip (1.2m x 10m) of grass with an Etesia mower (Etesia UK Ltd., Warwick, UK). All mown herbage from the strip was collected and weighed with a 0.1 kg (fresh weight) sub sample taken and dried at 90°C for 16 hours for the calculation of DM content. Ten compressed sward height (CSH) measurements were recorded before and after harvesting of the cut strip using a rising pasture plate meter with a steel plate (Jenquip, Fielding, New Zealand). Based on the aforementioned measurements, sward density was calculated as sward mass (kg DM ha⁻¹)/(pre-cutting – post-cutting CSH); and expressed as kg DM per cm per hectare (Delaby and Peyraud, 1998). Pre- and post-grazing CSH was also determined on each paddock before and after grazing by taking between 30 and 50 measurements across the diagonal of the paddock. The average paddock pre-grazing herbage mass (> target PGSH) was then calculated according to the following formula: Pre-grazing herbage mass (> target PGSH) = ((Pre-grazing CSH (cm) – target PGSH (cm)) x sward density); kg of DM per ha. Herbage harvested above target at each grazing was calculated as; herbage harvested = ((Pre-grazing CSH – target PGSH) x sward density) kg of DM per hectare. The proportion of herbage utilised to target PGSH and above 3.5 cm at each grazing was determined as using the method of Delaby and Peyraud, (1998) as Herbage utilised = (herbage removed/herbage available (> target PGSH and 3.5 cm) at each grazing). Total herbage harvested (> target PGSH) and herbage utilization was calculated as the sum of the herbage harvested (> target PGSH) and utilized at each grazing for each treatment. The proportion of surplus silage was calculated according to the following formula: proportion of surplus silage = ((Silage harvested (Including surplus grass; kg DM per ha)/(Silage utilised during winter housing period; kg DM per ha)-100). Based on observed differences in the quantities of herbage DM produced (kg DM per ha; > target PGSH) and herbage DM utilised (kg per ha) at each SR, a

calculation was carried out to determine a more accurate chemical N application rate per hectare using the following formula: Required chemical N = (surplus herbage (Total herbage harvested (kg DM per ha; > target PGSH) – Total herbage utilised; kg per ha) x kilogram of N applied per kilogram of DM produced above the target PGSH).

5.3.4 Sward morphology and chemical analysis

The pre-grazing leaf, stem and dead content of the sward was measured throughout the grazing season in the production years of 2014 and 2015, with a herbage sample representative of that available to the grazing animal cut to ground level using a hand shears. The herbage sample was separated into two sections above and below the target PGSH. The samples were further manually separated into leaf blades, stem and dead material proportions. The separated proportions were dried at 90°C for 16 hours for DM determination.

Dried herbage samples used to calculate DM content were used for quality determination. Samples were bulked based on treatment by grazing rotation and were subsequently analysed for DM, ash, neutral detergent fibre (NDF; Van Soest, 1963), acid detergent fibre (ADF), crude protein (CP; Leco FP-428; Leco Australia Pty Ltd., Baulkham Hills, New South Wales, Australia) and organic matter digestibility (OMD; Morgan et al., 1989).

5.3.5 Statistical analysis

For all analyses undertaken, the individual treatment grazing area was taken as the experimental unit. Pre- and post-grazing sward height, pre-grazing herbage mass (> target PGSH), sward density, proportion of herbage utilised to target PGSH and 3.5 cm, herbage DM production, utilisation, and the quantity of chemical N required were analysed using linear mixed models in PROC HP MIXED (SAS, 2012), with ewe PP, SR, and the interaction between ewe PP and SR, season, rotation, year included as fixed effects in the model. Herbage quality, the proportion of leaf, stem and dead in the swards were analysed using linear mixed models in PROC HP MIXED (SAS, 2012), with ewe PP, SR, and the interaction between ewe PP and SR, season, rotation, year included as fixed effects in the model.

5.4 Results

5.4.1 Meteorological data

Mean monthly recorded rainfall and temperature data for the three years of the study and the 30-year average are presented in Table 5.1. During the production years of 2013 and 2014, total rainfall was similar to the 30-year average with increased rainfall in April (+30.4 mm) and December (+97.1 mm) in 2013 and January (+65.8 mm), February (+89.9 mm) and May (+27.8 mm) in 2014. In 2015, total rainfall was higher than in 2013 and 2014, and was 382.9 mm greater than the 30-year average, with heavy rainfall occurring in January (+74.4 mm), March (+35.2 mm), July (+51.7 mm), November (+96 mm) and December (+176.2 mm). Mean daily temperature in the spring of 2013 was 2 °C below the average and in 2015 mean daily temperature were consistently lower than the 30-year average (1.1 °C below) from January to October.

5.4.2 Herbage growth rate and production

The effect of SR on mean daily herbage growth rate and annual herbage DM production per hectare is shown in Table 5.2. The mean daily herbage growth rate during the autumn and overall growing season was higher at the MSR and HSR relative to the LSR ($P<0.01$). Grazed herbage and total herbage DM production was highest at the HSR, intermediate at the MSR and lowest at the LSR ($P<0.001$), with the quantity of conserved herbage removed not differing with SR ($P>0.05$). Ewe PP had no effect on daily herbage growth rates or herbage DM production and no interaction between ewe PP and SR was observed on either parameter ($P>0.05$).

5.5.3 Sward characteristics and herbage utilization

The effect of ewe PP and SR on sward characteristics and herbage utilisation for the full grazing season is presented in Table 5.3. No significant interactions were observed between ewe PP and SR for any of the variables measured. The MP system utilised a higher proportion of herbage to 3.5 cm ($P<0.05$), but pre- and post-grazing sward heights, sward density, proportion of herbage utilised to target and herbage utilisation (grazed, silage and total) did not differ by ewe PP. Sward density was highest at the LSR and lowest at the HSR ($P<0.05$), with the MSR intermediate, however, the differences observed are relatively small and are

likely of biological significance. The proportion of herbage utilised to target PGSH was highest at the LSR ($P<0.001$) compared to the MSR and HSR which did not differ from each other. The proportion of herbage utilised to 3.5 cm was lowest at the LSR, intermediate at the MSR and highest at the HSR ($P<0.001$). The quantity of grazed grass, silage and total herbage utilised was highest at the HSR, intermediate at the MSR and lowest at the LSR ($P<0.001$). The proportion of surplus silage was highest at the LSR compared to the MSR and HSR which did not differ from each other. The duration of the grazing season reduced ($P<0.001$) as SR increased from 312 days at the LSR to 285 and 276 at the MSR and HSR, respectively (Table 5.3). Based on the difference between herbage DM production and utilisation relative to the N rate applied the actual N application rate required to support the grazing and winter feed requirements of the treatments were calculated to be 113, 145, and 179 kg N ha⁻¹ year⁻¹ for the LSR, MSR, and HSR treatments ($P<0.001$), with N requirement unaffected by ewe PP ($P>0.05$).

5.5.4 Pre- and post-weaning grazing characteristics

Prolificacy potential had no effect on sward grazing characteristics during the pre- and post-weaning periods ($P>0.05$; Table 5.4). Pre-weaning; herbage mass was significantly lower at the LSR ($P<0.05$) compared to the MSR and HSR which did not differ significantly from each other. The proportion of herbage utilised to the target PGSH during the pre- and post-weaning periods was significantly higher at the LSR ($P<0.001$) relative to the MSR and HSR, which did not differ from each other.

5.5.5 Morphological composition

There was no effect of ewe PP or interaction between ewe PP and SR observed for sward morphology ($P>0.05$). The effect of SR on proportion of leaf, stem, and dead material in the grazing swards from ground level and above and below imposed target PGSH from 2014 and 2015 are presented in Table 5.6. There was a higher proportion of leaf (+0.05; $P<0.05$) and lower proportion of dead material (-0.03; $P<0.05$) in MSR and HSR swards from ground level relative to the LSR swards, with the MSR and HSR not differing from each other. The proportion of leaf in the MSR and HSR swards above the target PGSH was 4% higher ($P<0.05$) relative to the LSR, with no significant differences observed in the proportion of stem and dead material. There was no effect of SR on the proportion of leaf, stem or dead

material below the target PGSH ($P>0.05$). Seasonal effects observed on sward morphology from ground level are illustrated in Figure 5.1.

The proportion of leaf in the grazing sward was higher in the spring ($P<0.001$) than in the summer and autumn periods. The proportion of stem material in the sward was highest during the summer ($P<0.001$), with spring and autumn periods not differing from each other, while the proportion of dead material was highest in the swards during the autumn periods ($P<0.001$) compared to the spring and summer periods.

5.5.6 Herbage quality

There was no effect of ewe PP or interaction between ewe PP and SR for herbage quality throughout the grazing season ($P>0.05$). Stocking rate had a significant effect on herbage OMD post-weaning, with the HSR treatment having a higher herbage OMD (+2.4 g per kg DM; $P<0.05$) compared to the mean of the LSR and MSR but SR had no effect on herbage quality at any other time period ($P>0.05$). Herbage CP was 26.1 g per kg DM higher in the pre-weaning period (213 g per kg DM) compared to the post-weaning period ($P<0.01$), with lower herbage OMD and UFL occurring in grazing rotations three to seven compared to rotations one and two (Figure 5.2; $P<0.001$). The UFL value in grazed herbage in rotation seven was lower than in rotation six ($P<0.05$). Significant effects of season on herbage quality were observed (Table 5.5), with herbage CP (+ 25.9 g per kg), OMD (+5.1 g per kg), and UFL (+0.09) highest during the spring grazing period ($P<0.001$) compared to the summer and autumn grazing periods which did not differ from each other. Herbage NDF (+60.6 g per kg) and ADF (+46.9 g per kg) was higher during the summer and autumn grazing periods ($P<0.001$). Sward DM content decreased as season progressed ($P<0.001$).

5.6 Discussion

The aim to achieve optimum herbage DM production, utilisation, and animal performance is widely acknowledged as a primary objective of grass-based ruminant production systems. Numerous studies have investigated the effects of SR on herbage DM production and utilisation in grazing systems but few have attempted to quantify the effects of ewe PP and SR on sward productivity in a temperate grass-based lamb production system. Earle et al. (2017) in a companion study evaluated ewe and lamb performance in the temperate grass-based lamb

production system described in this study and demonstrated the potential to increase output. Therefore, the objective of this companion study was to investigate the effect of ewe PP, SR, and their interaction on herbage DM production, utilization, quality, and sward morphology within a temperate grass-based lamb production system.

5.6.1 Grass production and utilisation

The productivity of the grazing sward is strongly influenced by grazing management decision rules imposed such as SR and PGSH (Baudracco et al., 2010; Fales et al., 1995; Macdonald, et al., 2008), which can have desired or undesired effects on herbage DM production, utilisation and sward structure (Fariña et al., 2011; Macdonald et al., 2008). The grazing management applied in this study is similar to that of Macdonald et al. (2008) and McCarthy et al. (2016) for dairy systems and aimed to optimise herbage utilisation within each SR, with a different target PGSH applied to each SR. Results therefore represent the likely implications of increasing ewe PP and SR when associated with an increase in grazing severity within a temperate grass-based lamb production system.

Sheep are widely acknowledged to have a greater ability to graze lower into the grazing sward relative to larger ruminant species, due to their more selective grazing behaviour (Broom and Arnold, 1986; Hodgson, 1982). Animals across all SR in the present study grazed below their targeted PGSH which is reflected in the greater than 1.0 proportion of herbage utilised to target. Ganche et al. (2013) recommended a target PGSH of 3.5 cm for the first grazing rotation and 4.5 cm during the main grazing season in a temperate grass-based dairy system in order to achieve optimum levels of herbage DM production. However, under the sheep grazing systems investigated in this study, the neutral effect of ewe PP and positive effect of increasing SR on the quantity of herbage harvested demonstrates the potential to graze below 4.5 cm during the main grazing season within a temperate grass-based lamb production system to maintain sward quality. The similar quantities of conserved herbage harvested across all SR was the result of greater quantities of surplus grass being removed as baled grass silage at the LSR (McCarthy et al., 2012; Valentine et al., 2009). This was a combined effect of the shorter winter housing period required by LSR treatment and perhaps the excess N surplus of 17 kg N per hectare per year calculated based on differences between herbage DM produced above the target PGSH and the quantities of herbage utilised. This demonstrates the

potential to adequately produce sufficient quantities of herbage at the LSR and MSR to meet animal grazing and winter feed requirements at a lower N application rate.

Stocking rate is a pivotal factor influencing herbage utilisation. The increase in the quantity of herbage utilised as SR increased in the present study was a combined effect of the higher SR and lower target PGSH imposed in the MSR and HSR treatments and supports previous findings observed in dairy cow grazing systems (Macdonald et al., 2008; McCarthy et al., 2012). The similar quantities of herbage utilised by the MP and HP ewes is an interesting finding and indicates no requirement to increase herbage DM production in order to support a more prolific flock relative to a medium prolificacy flock, despite the additional litter size weaned per ewe (Earle et al., 2016b). This is most likely a result of the lower mature body size and subsequent lower maintenance requirements of the HP ewes in the present study (AFRC, 1993; Kenyon et al., 2009).

5.6.2 Sward morphology

Lax or infrequent grazing of swards is often associated with low SR grazing systems, resulting in a reduction in herbage growth and high proportions of senescence losses within the grazing sward (Hoogendoorn et al., 1992; Korte et al., 1987). Higher SR and increased grazing severity are associated with increased proportions of leaf material and improved digestibility of grazing swards (Francis and Smetham, 1985; Lee et al., 2007) as was illustrated by the higher proportion of leaf material in the MSR and HSR swards compared to LSR swards in the present study. This demonstrates the positive effects of increasing SR and grazing severity on sward morphology and daily herbage growth rates, despite higher pre-grazing herbage masses above the target PGSH. This improvement in sward morphology can be primarily attributed to the lower PGSH and increased penetration of light into the MSR and HSR swards (Tuñon et al., 2013) and highlights the potential to graze at higher SR and lower into the grazing sward while maintaining a high content of leaf for grazing ewes and lambs. This in-turn may assist in alleviating declines in animal performance associated with increasing SR. The lack of effect of ewe PP on sward morphology in the present study suggests no difference in the grazing behaviour or effects of increased grazing competition in the HP treatment relative to the MP system (Earle et al., 2016b).

5.6.3 Herbage quality

The quality of pasture offered to grazing animals plays a vital role in determining herbage utilisation and animal performance within a grazing system (McCarthy et al., 2012). Increasing SR and grazing severity are commonly associated with improved sward quality (Lee et al., 2008; Tuñon et al., 2013). A study by Macdonald et al. (2008) observed an increase in herbage OMD and energy content but a quadratic decline in herbage NDF and ADF as both SR and grazing severity increased. In the present study, herbage quality did not differ by ewe PP, with SR having a tendency to increase herbage OMD post-weaning which is possibly the result of the lower PGSH imposed at the HSR. As previously mentioned sheep have the ability to graze lower into the grazing sward compared to cattle and this may have helped to maintain herbage quality and explain the lack of differences observed (Baudracco et al., 2011; Hodgson 1990).

McCarthy et al. (2012) noted a significant interaction between SR and season on herbage quality, with greatest differences occurring during the summer and autumn grazing periods. Although no SR effect were noted in the present study, the seasonal effects observed on sward quality in the current study follows a similar trend to that reported by McCarthy et al. (2016), with herbage CP, OMD and UFL highest in the spring period which is a possible explanation for the higher pre-weaning CP content observed. The decrease in herbage OMD and UFL content from grazing rotation one to seven highlights the seasonal reductions in herbage quality, particularly from the spring to summer and into the autumn grazing period. This is an important factor for lamb producers to consider, especially in intensively stocked grazing systems where the aim is to finish all lambs off pasture. The previously mentioned companion animal performance study Earle et al. (2017) demonstrated that as SR increased lamb daily growth rate decreased, with the number of days required to reach slaughter increasing resulting in a greater number of lambs grazing pasture in the autumn period.

5.7 Conclusion

Achieving a balance between the supply of high quality pasture and herbage utilization is paramount in optimising temperate grass-based lamb production systems. In the current study increasing SR and grazing severity increased herbage DM production, utilisation and the proportion of leaf material within the grazing sward, demonstrating the positive effects of SR on sward productivity within a temperate grass-based lamb production. The lack of interaction

between ewe PP and SR indicates the potential for sheep producers in temperate grazing regions to increase the ewe PP of their flock in conjunction with higher SR without negatively affecting sward productivity. The similar levels of herbage utilisation achieved by the two ewe PP investigated demonstrates the potential to increase output through increasing the ewe PP of a flock without needing to increase herbage DM production or utilisation.

5.8 Acknowledgments

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5.9 References

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Table 5.1 Monthly temperature and rainfall data during 2013, 2014 and 2015, and the mean for the previous 30-year period

Month	January	February	March	April	May	June	July	August	September	October	November	December	Total
Mean rainfall (mm)													
2013	132	47	37	102	97	61	102	73	48	120	100	220	1139
2014	183	178	103	48	103	39	92	105	10	141	139	124	1264
2015	191	69	130	75	138	45	138	115	93	67	216	299	1576
30 yr.	117	88	95	72	75	80	87	108	100	129	120	123	1193
Mean temperature (°C)													
2013	5.2	4.7	3.8	7.2	10.2	13.3	17.5	15	13.6	11.7	6.4	6.9	-
2014	5.3	5.5	6.9	10.1	11.5	14.4	16.1	13.8	13.9	10.5	6.9	5.6	-
2015	4.9	4.5	6.0	8.3	9.8	12.4	13.5	13.5	12.3	10.0	9.0	8.1	-
30 yr.	5.3	5.5	7.0	8.7	11.4	13.8	15.6	15.4	13.3	10.3	7.5	5.6	-

Table 5.2 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on daily herbage growth rates and on annual herbage dry matter (DM)³ production over the 3 year period (2013–2015)

Parameter	PP				SR			<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Herbage growth rate (kg DM per ha per day)										
Mean	33.9	35.1	0.51	32.0 ^a	35.5 ^b	36.0 ^b	0.06	NS	**	NS
Spring	20.9	21.0	0.78	20.2	21.1	21.6	0.96	NS	NS	NS
Summer	64.1	68.3	1.38	62.6	67.4	68.5	1.55	NS	NS	NS
Autumn	46.2	46.8	0.98	40.3 ^a	48.3 ^b	49.3 ^b	1.11	NS	***	NS
Winter	5.4	4.5	0.51	4.8	5.2	4.7	0.59	NS	NS	NS
Annual herbage harvested (kg DM per ha per year)										
Grazed	8633	8700	232.1	6864 ^a	8479 ^b	10655 ^c	284.3	NS	***	NS
Silage	2271	2708	171.4	2710	2364	2392	209.9	NS	NS	NS
Total	10903	11407	283.5	9574 ^a	10843 ^b	13047 ^c	347.2	NS	***	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³DM = Dry matter.

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 5.3 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on sward characteristics and herbage utilisation

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Pre-grazing herbage mass (> target PGSH ³ ; kg DM per ha)	1236	1296	28.4	1199 ^a	1282 ^{ab}	1316 ^b	34.0	NS	*	NS
Pre-grazing herbage height (cm)	8.0	8.2	0.09	8.2 ^a	8.1 ^a	7.8 ^b	0.11	NS	*	NS
Post-grazing herbage height (cm)	4.0	4.0	0.05	4.3 ^a	4.1 ^b	3.6 ^c	0.06	NS	***	NS
Density (kg DM per cm)	310	311	0.5	312 ^a	310 ^{ab}	309 ^b	0.6	NS	*	NS
Herbage Utilised (kg DM per ha per year)										
Grazed	8954	8828	243.3	7381 ^a	8482 ^b	10809 ^c	298.0	NS	***	NS
Proportion of herbage utilised to target PGSH ³	1.05	1.02	0.010	1.06 ^a	1.01 ^b	1.02 ^b	0.014	NS	***	NS
Proportion of herbage utilised (to 3.5 cm)	0.89	0.86	0.008	0.82 ^a	0.85 ^b	0.95 ^c	0.010	*	***	NS
Silage	1496	1519	53.5	926 ^a	1555 ^b	2040 ^c	65.5	NS	***	NS
Proportion of surplus silage	0.82	1.01	0.205	2.07 ^a	0.48 ^b	0.19 ^b	0.251	NS	***	NS
Total	10449	10347	246.66	8306 ^a	10038 ^b	12849 ^c	302.1	NS	***	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³Target PGSH = Target post-grazing sward height (LSR = 4.55, MSR = 4.15, and HSR = 3.75 cm).

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 5.4 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on pre- and post-weaning sward characteristics

Parameter	PP			SR				P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
<u>Pre-weaning</u>										
Herbage mass above target PGSH ³ (kg DM per ha)	903	976	0.016	833 ^a	985 ^b	1001 ^b	0.019	NS	*	NS
Pre-grazing herbage height (cm)	6.9	7.1	0.1	7.1	7.2	6.8	0.1	NS	NS	NS
Post-grazing herbage height (cm)	4.0	4.1	0.55	4.2 ^a	4.1 ^a	3.7 ^b	0.07	NS	***	NS
Prop. utilised to target PGSH ³	1.05	1.01	36.4	1.07 ^a	1.01 ^b	1.01 ^b	44.3	NS	***	NS
<u>Post-weaning</u>										
Herbage mass above target PGSH ³ (kg DM per ha)	1620	1669	48.9	1575	1657	1702	58.2	NS	NS	NS
Pre-grazing herbage height (cm)	9.2	9.4	0.16	9.4	9.3	9.1	0.19	NS	NS	NS
Post-grazing herbage height (cm)	4.1	4.2	0.06	4.4 ^a	4.2 ^b	3.7 ^c	0.08	NS	***	NS
Proportion of utilised to target PGSH ³	1.02	0.99	0.015	1.05 ^a	0.99 ^b	0.97 ^b	0.019	NS	***	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³Target PGSH= Target post-grazing sward height (LSR = 4.55, MSR = 4.15, and HSR = 3.75 cm).

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 5.5 Effect of season on herbage quality (> 3.5 cm; g per kg dry matter (DM) unless stated otherwise)

Parameter	Season			SEM	<i>P-value</i>
	Spring	Summer	Autumn		
Dry matter (%)	20.6	17.7	15.7	0.18	***
Ash	97.5 ^a	102 ^a	109 ^b	2.55	*
Organic matter	903 ^a	898 ^a	891 ^b	2.56	**
Crude protein	215 ^a	184 ^b	195 ^b	5.18	***
Crude fibre	212 ^a	229 ^b	222 ^b	2.96	***
Neutral detergent fibre	421 ^a	482 ^b	481 ^b	5.54	***
Acid detergent fibre	209 ^a	253 ^b	259 ^b	3.87	***
Organic matter digestibility	772 ^a	727 ^b	714 ^b	0.60	***
Unite fourrage laite (UFL per kg DM)	0.97 ^a	0.89 ^b	0.86 ^b	0.01	***

a,b,c Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

Table 5.6 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on leaf, stem, and dead proportions during the 2014 and 2015 grazing seasons

Parameter	PP			SR				<i>P-value</i>		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR	PPxSR
Sward horizon (from ground level)										
Leaf proportion	0.67	0.67	0.013	0.64 ^a	0.68 ^b	0.70 ^b	0.015	NS	*	NS
Stem proportion	0.21	0.20	0.009	0.22	0.20	0.20	0.012	NS	NS	NS
Dead proportion	0.12	0.12	0.044	0.14 ^a	0.11 ^b	0.11 ^b	0.010	NS	*	NS
Sward horizon (> target PGSH ³)										
Leaf proportion	0.76	0.77	0.012	0.74 ^a	0.78 ^b	0.78 ^b	0.014	NS	*	NS
Stem proportion	0.15	0.14	0.009	0.16	0.14	0.14	0.011	NS	NS	NS
Dead proportion	0.83	0.09	0.007	0.10	0.08	0.08	0.008	NS	NS	NS
Sward horizon (< target PGSH ³)										
Leaf proportion	0.42	0.41	0.018	0.40	0.42	0.42	0.021	NS	NS	NS
Stem proportion	0.38	0.38	0.013	0.38	0.37	0.39	0.016	NS	NS	NS
Dead proportion	0.20	0.21	0.012	0.22	0.20	0.19	0.014	NS	NS	NS

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha.

³Target PGSH = Target post-grazing sward height (LSR = 4.55, MSR = 4.15, and HSR = 3.75 cm).

^{a,b,c} Within rows, means with differing superscripts significantly differ.

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

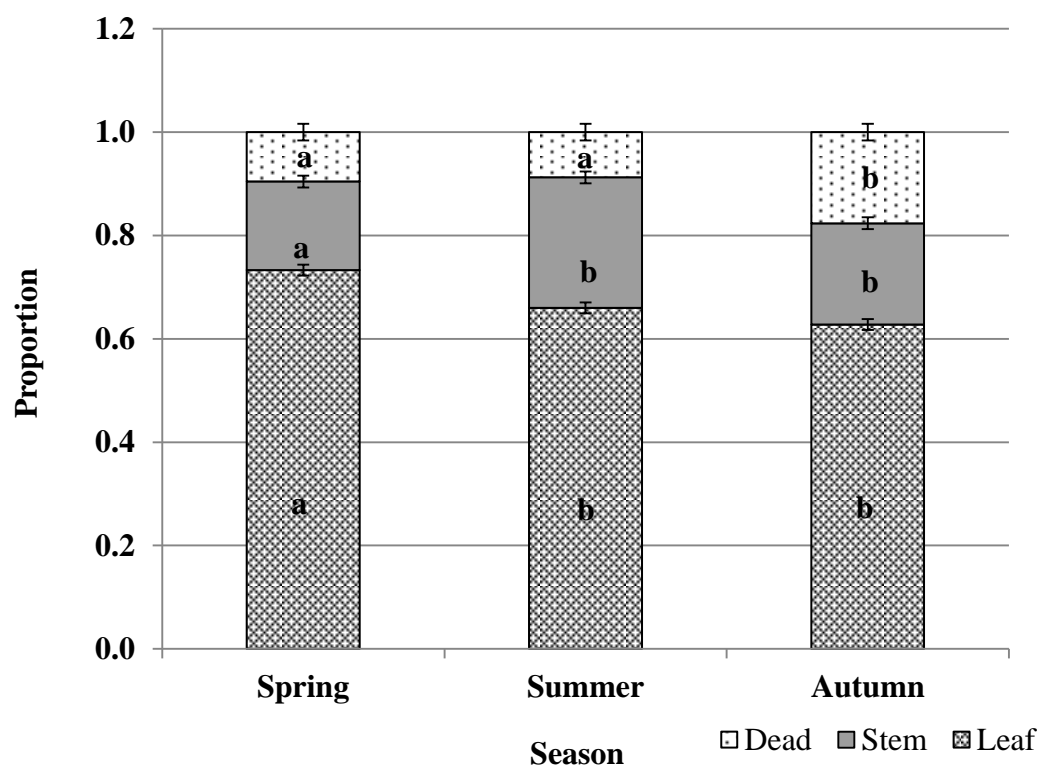


Figure 5.1 The leaf, stem and dead proportions (from ground level) in the grazed swards in 2014 and 2015. Error bars represent mean standard error.

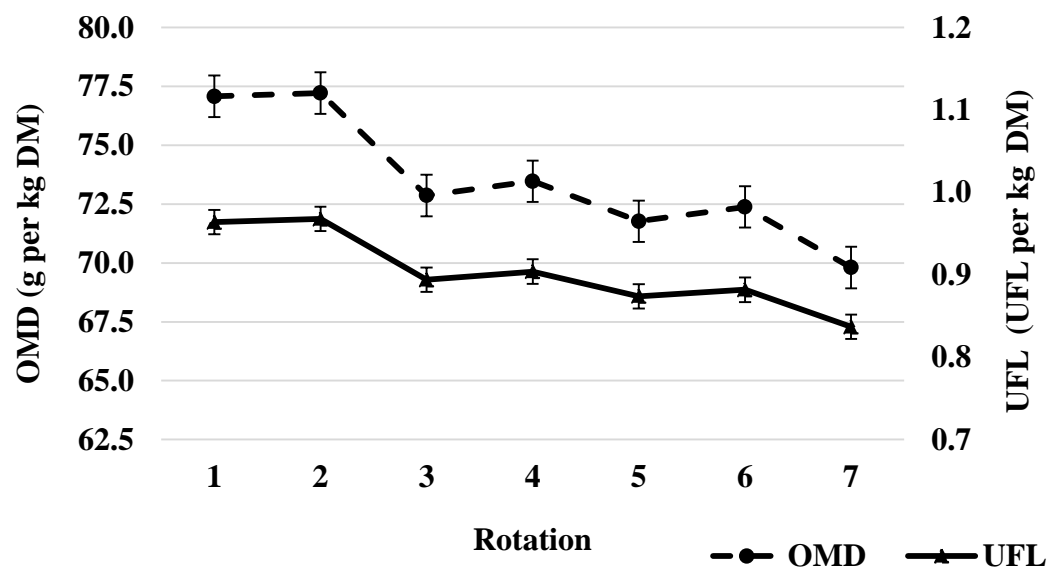


Figure 5.2 Effect of grazing rotation on sward organic matter digestibility (OMD) and Unite fourrage laite (UFL) levels. Error bars represent mean standard error.

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6. Chapter 6

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**Measures of lamb production efficiency in a temperate grass-
based system differing in ewe prolificacy potential and stocking
rate**

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6.1 Abstract

The objective of this study was to quantify the effect of ewe prolificacy potential (PP; predicted number of lambs born per ewe per year) as dictated by sire breed type and stocking rate (SR; ewes per ha) on ewe production efficiency (kg lamb live weight weaned: kg ewe live weight mated), lamb growth, lamb carcass output, and dry matter (DM; kg) and energy (UFL; Unite fourrage laite per kg DM) consumption in a temperate grass-based lamb production system. The study was a 2 x 3 factorial design, consisting of two differing ewe PP (MP – Suffolk-sired crossbred ewes and HP – Belclare-sired crossbred ewes) and three SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) and high (HSR: 14 ewes per ha). The HP treatment weaned more lambs per ewe and per hectare ($P < 0.01$), yielded a higher ADG per hectare ($P < 0.001$), produced an additional 50 kg of lamb carcass per hectare ($P < 0.05$) and required 13% less DM and UFL to produce a kilogram of lamb carcass ($P < 0.001$). High PP ewes had a 4% higher production efficiency ($P < 0.05$). Ewe PP had no effect on the total quantity of DM and UFL consumed per ewe and lamb unit ($P > 0.05$). Increasing SR increased the number of lambs weaned per hectare ($P < 0.001$) and increased lifetime lamb ADG per hectare ($P < 0.001$). Lamb carcass output (kg) per hectare was highest at the HSR, intermediate at the MSR, and lowest at the LSR ($P < 0.001$). The quantity of DM and UFL consumed per kilogram of lamb carcass produced per hectare increased as SR increased ($P < 0.001$). In conclusion, results from this study demonstrate HP ewes to be more efficient in the production of lamb. Increasing SR provides the opportunity to increase lamb carcass output per hectare, however achieving this increase in output required additional DM and UFL per ewe and lamb unit above 12 ewes per hectare.

6.2 Introduction

The production of lamb in temperate grass-based production systems is principally based upon the utilisation and conversion of herbage into lamb carcass. Successful grazing systems require animals that are adapted to achieve large intakes of herbage and can efficiently convert feed into a high value product. At present, the lamb production systems are limited by efficiencies at which they operate, such as number of lambs weaned per ewe and the level of herbage utilised per hectare (Keady et al., 2009; Young et al., 2010). In order to remain competitive, improvements in the efficiency of such systems is of paramount importance.

Ewe prolificacy potential (PP; predicted number of lambs born per ewe per year; Davis et al., 2006) and stocking rate (SR; ewes per ha; Allen et al., 2011) are two of the most influential factors affecting lamb output (Keady et al., 2009) and the efficiency at which feed resources are utilised in grass-based lamb production systems (Young et al., 2010). Previous research has shown that ewe PP and SR can be increased without negatively impacting on key flock performance indicators and sward productivity (Earle et al., 2017a; 2017b). However, previous studies have tended to focus on efficiency at an individual animal and sward level rather than their interaction on overall system efficiency and the conversion of feed resources into lamb carcass.

In grass-based ruminant production systems, the efficient use of feed resources and increased output per hectare are widely acknowledged as key drivers of productivity (Macdonald et al., 2008). Although, at present, there is a paucity of information in the literature in regard to the effects of ewe PP, SR, and their interaction on efficiency of lamb production. Therefore the objective of this study was to investigate the effect of ewe PP, SR, and their interaction on the measures of ewe, lamb, and system efficiency in a temperate grass-based production system.

6.3 Materials and Methods

The study was conducted over a three year period from October 2012 to December 2015 at the Sheep Research Demonstration Farm, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co Galway, Ireland (54° 80'N; 7°25'W). All procedures involving ewes and lambs in the study were conducted under license from the Irish

Department of Health in accordance with the Cruelty to Animals Act 1876 and the European Communities Regulations, 1994.

6.3.1 Study Design and Flock Management

The experimental design and flock management are described in detail in Earle et al.(2017a) but in summary a 2 x 3 factorial design, consisting of two differing ewe PP (Hanrahan, 1994) as dictated by sire breed and three SR was applied. This included 180 medium prolificacy potential (MP – Suffolk-sired crossbred ewes) and 180 high prolificacy potential ewes (HP – Belclare-sired crossbred ewes), which were assigned to one of three SR: low (LSR; 10 ewes per ha), medium (MSR; 12 ewes per ha) or high (HSR: 14 ewes per ha).

All ewes were mated to Charollais rams over a 6 week period in October and November each year. Ewes were housed on completion of the closing grazing rotation (HSR = early December, MSR = late December and LSR = mid-January). Upon housing, based on AFRC (1993) ewes were offered a maintenance diet during mid-pregnancy of baled grass silage (mean 67.5 dry matter digestibility; DMD) ad libitum. In late pregnancy, ewes were offered higher quality baled grass silage (mean 72.7 DMD) ad libitum. Detailed descriptions of grazed and conserved herbage quality are described by Earle et al. (2017a). Ewes were pregnancy scanned d 90 after mating start date and concentrate supplementation was introduced to ewes in late pregnancy as described by Earle et al. (2017a). Lambing commenced in early March each year. Post-lambing, ewes and lambs were turned out to pasture, with concentrate supplementation provided to ewes for a short time period in 2013 and 2014 to meet ewe energy requirements during early lactation when pasture availability failed to meet energy requirements. Target pre-grazing sward heights were 7.0 to 9.0 cm (1200 to 1500 kg DM per ha) across all treatments. All treatments grazed to a targeted post-grazing sward height of 3.50 cm for the first grazing rotation and to post-grazing sward height targets of 4.55, 4.15, and 3.75 cm for the LSR, MSR and HSR groups, respectively for the remaining pre-weaning period. Post-weaning a leader-follower grazing system was operated, with LSR, MSR, and HSR groups grazing to targeted post-grazing sward heights of 5.55, 5.15, and 4.75 cm for lambs and 4.55, 4.15, and 3.75 cm for ewes, respectively. Lambs were weaned on average at 14 weeks of age and were drafted for slaughter at live weights of 42, 43, 44, 45, and 46 kg in the months June, July, August, September and October, respectively

in order to produce a target carcass weight of 20 kg. This was necessitated due to reductions in kill out proportions as a lamb matures. When grass supply dropped below 50 kg dry matter (DM) per ewe per hectare or lamb growth rate dropped below 100 g per d, lambs not slaughtered were removed from their grazing area and finished indoors on grass silage *ad libitum* and concentrate supplementation. This was done to maintain adequate grass supplies for ewes during mating and early pregnancy.

6.3.2 Animal Measurements

6.3.2.1 Ewe production measures

Ewe live weight (kg) was recorded at mating, pregnancy scanning, lambing, 6 weeks post-lambing, and weaning. The number of lambs born and weaned per ewe and per hectare and the live weight of lamb weaned per ewe and per hectare were recorded.

6.3.2.2 Lamb production measures

Lambs were weighed at 2 week intervals from 6 weeks of age to slaughter and ADG was calculated accordingly. Pre-weaning lamb ADG = weaning live weight (kg) minus birth weight (kg) divided by age at date weighed and lifetime lamb ADG = drafting live weight (kg) minus birth weight (kg) divided by days required to reach slaughter.

6.3.2.3 Efficiency measures

Production efficiency per ewe and per hectare was calculated as the ratio of lamb live weight weaned per ewe (kg) and per hectare (kg) divided by ewe mated live weight per ewe (kg) and per hectare (kg).

The quantity of DM and energy (UFL; Unite fourrage laite per kg DM) consumed per hectare per d as grazed herbage from turn-out (d 0) to 6 weeks post-lambing, pre-weaning (d0 to 14 weeks), and for the full grazing season was calculated based on herbage production data reported by Earle et al. (2017b) as follows: Daily grass DM and UFL consumed per hectare = DM or UFL consumed per hectare divided by the No. of d grazing.

The quantity of DM and UFL consumed as grazed herbage, conserved herbage and concentrates on a per ewe and lamb unit basis and per kilogram of lamb carcass produced was calculated based on herbage production data and concentrate feeding reported by Earle et al. (2017a, 2017b) as follows; Per ewe and lamb unit = Total DM or UFL per hectare divided by the No. of ewes per ha; per kilogram of lamb carcass = Total DM or UFL per hectare divided by the kilograms of lamb carcass produced per ha.

Proportion of lamb carcass produced from grazed herbage only was calculated as follows = lamb carcass produced per hectare from grazed herbage (without supplementation) divided by total lamb carcass produced per hectare.

6.3.3 Statistical Analysis

6.3.3.1 Ewe production measures

The effect of ewe PP, SR, and their interaction on the number of lambs born and weaned per ewe were analysed using a linear mixed model in PROC GLM (SAS, 2012) with ewe PP, SR, year, and the interaction between PP and SR included as fixed effects.

6.3.3.2 Lamb production measures

The effect of ewe PP, SR, and their interaction on lamb ADG per hectare and lamb carcass output were analysed using a linear mixed model in PROC GLM (SAS, 2012) with ewe PP, SR, year, and the interaction between PP and SR included as fixed effects

6.3.3.3 Efficiency measures

The effect of ewe PP, SR, and their interaction on ewe production efficiency, the proportion of lamb carcass produced from grazed herbage only, the amount of DM and UFL consumed per hectare per d from turn-out (d0) to 6 weeks post-lambing, pre-weaning, and the total amount of DM and UFL consumed as grazed herbage, conserved herbage, and concentrates per ewe and lamb unit and per kg of lamb carcass produced were analysed using a linear mixed model in PROC GLM (SAS, 2012) with ewe PP, SR, year, and the interaction between PP and SR included as fixed effects.

6.4 Results

6.4.1 Output per ewe and production efficiency

No ewe PP by SR interactions was observed for any of the parameters investigated. High PP ewes had a higher number of lambs born per ewe (+0.20 lambs; $P<0.001$; Table 6.1) and per hectare (+ 1.5 lambs; $P<0.05$) and weaned an extra 0.18 lambs per ewe ($P<0.01$) and 2.01 lambs per hectare ($P<0.01$). Stocking rate had no effect on the number of lambs born or weaned per ewe ($P>0.05$). However, the number of lambs born and weaned differed on a per hectare basis with the lowest number reported at the LSR, intermediate at the MSR, and highest at the HSR ($P<0.001$). High PP ewes had a 4% higher production efficiency per ewe and per hectare ($P<0.05$). Stocking rate had no effect on production efficiency per ewe ($P>0.05$). The LSR treatment had a 5% higher production efficiency per hectare compared to the HSR ($P<0.05$), with the MSR treatment not differing from either the LSR or HSR treatment.

6.4.2 Lamb growth

The effect of ewe PP and SR on individual lamb growth is quantified elsewhere (Earle et al., 2017a). Pre-weaning and lifetime lamb ADG per hectare is illustrated in Figures 6.1 and 6.2. From birth to weaning (Fig. 6.1), the HP treatment achieved a higher ADG per ha compared to the MP treatment ($P<0.001$), with the HP treatment achieving a 0.45 kg higher lifetime (birth to slaughter) lamb ADG per ha compared to the MP treatment ($P<0.001$; Fig. 6.2). Total lifetime lamb ADG per ha was lowest at the LSR, intermediate at the MSR, and highest at the HSR ($P<0.001$).

6.4.3 Daily consumption of grazed herbage

Ewe PP had no effect on the quantity of DM and UFL consumed per ha per d while grazing at any of the measured time-periods (Table 6.2; $P>0.05$). From turnout to 6 weeks, the LSR treatment consumed a lower quantity of DM and UFL per hectare per d compared to the MSR and HSR treatment ($P<0.05$), which did not differ from each other. From turnout to 14 weeks, the HSR treatment consumed a higher quantity of DM and UFL per hectare per d compared to the LSR and MSR ($P<0.05$) which did not differ from each other. The average quantity of

DM and UFL consumed per hectare per d for the full grazing season was lowest at the LSR, intermediate at the MSR, and highest at the HSR ($P<0.01$).

6.4.4 Total dry matter and energy consumption

The quantities of DM and UFL consumed per ewe and lamb unit and per kilogram of lamb carcass produced are shown in Tables 6.3 and 6.4. Ewe PP had no effect on the total quantity of DM and UFL consumed as grazed herbage DM and UFL or the total quantity of DM and UFL (includes conserved herbage and concentrates) consumed per ewe and lamb unit ($P>0.05$). The HP treatment consumed a higher quantity of DM and UFL as conserved herbage and concentrates per ewe and lamb unit ($P<0.001$). The quantity of DM and UFL consumed per ewe and lamb unit as total herbage (grazed and conserved) and total DM and UFL was highest at the HSR ($P<0.001$) but did not differ between the LSR and MSR.

The HP treatment consumed 4.1 kg DM and 3.7 UFL less per kilogram of lamb carcass produced relative to the MP treatment ($P<0.001$). The total quantity of DM and UFL consumed per kilogram of lamb carcass produced was lowest at the LSR, intermediate at the MSR and highest at the HSR ($P<0.001$). The proportion of UFL consumed per ewe and lamb unit in the MP treatment was lower than the HP treatment as follows: grazed herbage was 83.7 and 84.4%, conserved herbage 3.8 and 4.1% and concentrates 11.8 and 12.1% ($P<0.001$). On a proportional basis grazed herbage accounted for 86.8, 83.0, and 82.4% of total UFL consumed per ewe and lamb unit in the LSR, MSR, and HSR treatments, respectively. Conserved herbage accounted for 9.4, 13.1, and 13.4% and concentrates accounted for 3.8, 3.9, and 4.2% of total UFL consumed per ewe and lamb unit in the LSR, MSR, and HSR treatments ($P<0.001$), respectively.

6.4.5 Lamb carcass output

The HP treatment had a higher total lamb carcass output per hectare (+50 kg; $P<0.05$; Table 6.5) compared to the MP treatment. The proportion of lamb carcass produced from grazed herbage only, did not differ by ewe PP (85% for both the MP and HP treatments; $P>0.05$). Lamb carcass output per hectare was highest at the HSR, intermediate at the MSR, and lowest at the LSR ($P<0.001$). A higher proportion of the total quantity of lamb carcass produced at the HSR was from grazed herbage supplemented with conserved herbage and concentrates

relative to the LSR ($P < 0.05$), with the MSR not differing from either. The proportion of lamb carcass that was produced from grazed herbage with supplementation did not differ by ewe PP ($P > 0.05$).

6.5 Discussion

The productivity of temperate grass-based lamb production systems is a function of the number of lambs reared per ewe, lamb carcass output per ha and optimal use of feed resources (Keady et al., 2009). The use of increased ewe PP and higher SR coupled with improved grassland management provides the opportunity to significantly increase flock productivity (Earle et al., 2017a; 2017b), however the efficiency at which such increases in productivity are achieved must be evaluated. Therefore, the aim of the present study was to investigate the effects of ewe PP, SR, and their interaction on the efficiency of lamb production in a temperate grass-based lamb production system and the factors influencing it.

The use of prolific ewe genotypes is one strategy available to producers to increase flock output. In the present study, the greater number of lambs weaned per ewe and per hectare in the HP treatment can be primarily attributed to the superior genetic prolificacy potential of the HP ewes for greater litter size (Hanrahan, 1994). In addition, the lack of effect of SR on the number of lambs weaned per ewe and the increased number of lambs weaned per hectare is a positive finding as maintaining reproductive performance levels is essential to increasing lamb output through increases in SR.

The production efficiency of the breeding ewe is typically measured as the proportion of lamb live weight weaned to ewe live weight mated and is a commonly used benchmarking tool for producers (Dawson and Carson, 2002; Wolf et al., 2014). Numerous factors influence the production efficiency of the breeding ewe including the number of lambs weaned per ewe, lamb live weight at weaning, and the mature weight of the breeding ewe, all of which in-turn are governed by genetics, nutrition and flock management. Typical ewe production efficiency targets for the sheep industry range from 0.65 to 0.85 (SRUC, 2017). The ewe production efficiencies recorded in the present study are within this range, with the 4% higher production efficiency per ewe and hectare in the HP treatment largely attributed to the greater litter size and lamb live weight weaned per ewe and per hectare and the lower mature live weight of the

HP ewe (Earle et al., 2017a). The differences in production efficiency per hectare recorded between the LSR and HSR treatment is a result of the lower lamb live weight weaned per hectare in the HSR treatment relative to the LSR treatment.

The daily herbage consumption of grazing ruminants is influenced by both the physical attributes of grazing swards (sward height, density, herbage quality and allowance) and the digestive apparatus of the grazing animal (Newman et al., 1994). The lack of effect of ewe PP on the total quantity of DM and UFL consumed per ewe and lamb unit in the present study is probably a combined result of the lower maintenance requirements of the HP ewes (AFRC, 1993) and the ability of HP progeny to achieve a lifetime ADG equivalent to that of MP progeny (Earle et al., 2017a). One key biological factor identified in previous research to significantly influence the efficiency of feed consumption in grazing ruminants is gastrointestinal tract (GIT) size. Beecher et al. (2014) observed smaller sized jersey cow genotypes to have a higher GIT size than in larger sized Holstein Friesian cow genotypes and confirmed previous assumptions by Prendiville et al. (2010) of differences in DM consumption per kg body weight to be the result of differences in GIT size in grazing ruminants. While GIT size was not measured in the present study it is a possible explanation in addition to the lower maintenance requirements of the HP ewes for the increased feed efficiency of the HP treatment. In addition, the lack of effect of ewe PP on the daily herbage consumption in the present study concurs with previous findings by Gibb and Treacher (1982) and Morris and Kenyon (2010) with no effect of litter size reared per ewe on daily herbage consumption. It further illustrates conclusions made by Kenyon et al. (2009) that the higher lamb live weight weaned from ewes of a large mature body size doesn't compensate for their additional maintenance requirements and that it is more efficient to produce more lambs from a greater number of small ewes than a smaller number of larger ewes.

It is widely acknowledged that as SR increases herbage availability and consumption will increase per hectare and decline on an individual animal basis (Baudracco et al., 2011; Gibb and Treacher, 1981) corroborating results in the present study. This combined with the lower individual lifetime lamb ADG and longer winter housing periods as SR increased (Earle et al., 2017a; 2017b) contributed to the higher total quantity of DM and UFL consumed per ewe and lamb unit above 12 ewe per hectare and per kilogram of carcass produced at all stages as SR increased.

Carcass output per hectare in a lamb production system is both a function of both the litter size reared per ewe and carcass weight of individual lambs. The higher carcass output per ha in the HP treatment in the present study can be primarily attributed to the greater number of lambs slaughtered per ewe and per hectare and the significantly 0.4 kg higher carcass weight of progeny born to HP ewes (Earle et al., 2017a). Many studies have previously demonstrated output per hectare to increase as SR increases in ruminant production systems (Cowan et al., 1975; Macdonald et al., 2008). The increase in lamb carcass output per hectare as SR increases concurs with previous findings by Keady et al. (2009). However, one key difference in the management practices applied in the present study compared to that applied by Keady et al. (2009) is that in the present study lambs were un-supplemented at pasture throughout the grazing season, with concentrate supplementation only provided to small proportions of lambs remaining in each treatment at the end of the grazing season, as demonstrated in the high proportions of lamb carcass produced from grazed herbage only in all treatments in the present study.

Efficiency is best expressed as the unit of output per unit of input of an entire production system and can be measured either in physical (biological) or economic terms (Dickerson, 1969). Maximising the proportion of grazed herbage in the diet of the breeding ewe and her offspring and the efficiency at which feed/energy is converted into lamb carcass is a key determinant of the productivity of temperate grass-based lamb production systems (Earle et al., 2016c). This combined with the lower associated production costs of grazed herbage compared to alternative feed sources (Finneran et al., 2010) provides producers in temperate grazing regions with the opportunity to produce lamb in a lower cost and more sustainable manner. The increase in lamb carcass output per hectare and 13% higher feed efficiency of the HP system demonstrates it to be more efficient in the production of lamb carcass. This in addition to the 85% of total carcass output produced from grazed herbage in the HP treatment is an important finding; as herbage production and utilisation level ultimately limit the level of animal production that can be achieved within grazing systems (MacDonald et al., 2001). This finding demonstrates not only the potential to increase lamb carcass output from grazed herbage but also the potential to increase the efficiency at which herbage resources are converted into carcass. The lower quantity of DM and UFL consumed per kilogram of lamb carcass produced in the LSR treatment is a result of higher lifetime lamb ADG, lower days to slaughter, and shorter winter housing period for LSR ewes. However, the lack of difference in many of the efficiency parameters measured in the present study such as ewe production

efficiency per hectare, total DM and UFL consumed per ewe and lamb unit and the proportion of lamb carcass produced from grazed herbage would suggest that the LSR and MSR systems are equally efficient in the production of lamb and utilisation of feed resources.

In conclusion, increasing ewe PP increased the number of lambs weaned per ewe and per ha, increased lamb carcass output and enhanced the efficiency of lamb production in a temperate grass-based production system. The lack of interaction between ewe PP and SR demonstrates the potential to increase ewe PP along with SR in a temperate grass-based lamb production system. The use of higher SR in the present study illustrates the potential to increase the number of lambs weaned per hectare and lamb carcass output per hectare. However, the higher quantities of DM and UFL consumed per ewe and lamb unit above 12 ewes per hectare would indicate a decline in the efficiency of production of lamb at 14 ewes per hectare.

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Table 6.1 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lamb output and production efficiency³ (Least Square Means \pm SEM)

Parameter	PP			SR				
	MP	HP	SEM	LSR	MSR	HSR	SEM	P
Born litter size								
No. lambs per ewe	1.87	2.07	0.031	2.00	1.92	1.99	0.038	*
No. lambs per ha	22.1	23.6	0.45	19.2 ^a	22.7 ^b	26.7 ^c	0.55	*
Weaned litter size								
No. lambs per ewe	1.5	1.68	0.031	1.63	1.57	1.56	0.039	*
No. lambs per ha	18.0	20.1	0.42	16.3 ^a	18.8 ^b	21.9 ^c	0.52	*
Production efficiency								
Production efficiency per ewe	0.64	0.68	0.013	0.68	0.65	0.65	0.015	*
Production efficiency per ha ⁴	0.64	0.68	0.011	0.69 ^a	0.66 ^{ab}	0.64 ^b	0.014	*

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential,

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

³Production efficiency = kg lamb live weight weaned: kg ewe live weight mated,

⁴Production efficiency per ha = kg lamb live weight weaned per ha: kg ewe live weight mated per ha,

^{a,b,c} Within rows, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05),

Table 6.2 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on grazed grass dry matter (DM)³ and energy (UFL)⁴ consumed per ha per d (Least Square Means \pm SEM)

Parameter	PP			SR				P-value	
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
DM per ha per d, kg									
0-6 weeks	23.2	22.3	0.46	19.0 ^a	23.6 ^b	25.6 ^b	0.56	NS	*
0-14 weeks	27.1	27.4	0.78	22.1 ^a	26.0 ^a	33.5 ^b	0.96	NS	*
Full grazing season	31.1	30.6	0.88	23.7 ^a	29.8 ^b	39.2 ^c	1.07	NS	***
UFL per ha per d, UFL per DM									
0-6 weeks	22.4	21.5	0.44	18.3 ^a	22.7 ^b	24.8 ^b	0.54	NS	*
0-14 weeks	26.2	26.3	0.76	21.3 ^a	25.1 ^a	32.4 ^b	0.09	NS	*
Full grazing season	28.3	27.9	0.80	21.5 ^a	27.1 ^b	35.6 ^c	0.98	NS	***

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential,

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

³DM = Dry matter,

⁴UFL = Unite fourrage laite,

^{a,b,c} Within rows, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05),

Table 6.3 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on the quantity of dry matter (DM)³ consumed as grazed herbage, conserved herbage, concentrates and total DM on a per ewe and lamb unit basis and per kilogram of carcass produced (Least Square Means \pm SEM)

Parameter	PP			SR			P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
DM consumed per ewe and lamb unit⁴									
Grazed herbage	743	735	6.0	738 ^a	707 ^b	772 ^c	7.3	NS	***
Conserved herbage	122	124	0.6	93 ^a	130 ^b	146 ^c	5.8	*	***
Total herbage	864	859	6.6	831 ^a	837 ^a	918 ^b	8.1	NS	***
Concentrates	27.3	29.5	0.24	26.2 ^a	27.3 ^b	31.7 ^c	0.29	***	***
Total DM	892	889	6.8	857 ^a	864 ^a	950 ^b	8.3	NS	***
DM consumed per kilogram of carcass									
Grazed herbage	25.7	22.2	0.26	23.0 ^a	23.1 ^a	25.7 ^b	0.31	***	***
Conserved herbage	4.2	3.8	0.05	2.9 ^a	4.2 ^b	4.8 ^c	0.06	***	***
Total herbage	30.0	26.0	0.31	25.9 ^a	27.4 ^b	30.6 ^c	0.38	***	***
Concentrates	0.95	0.89	0.006	0.82 ^a	0.89 ^b	1.05 ^c	0.008	***	***
Total DM	31.0	26.9	0.31	26.7 ^a	28.3 ^b	31.6 ^c	0.38	***	***

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential,

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

³DM = dry matter,

^{a,b,c} Within rows, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05),

Table 6.4 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on the quantity energy (UFL; Unite fourrage laite)³ consumed as grazed herbage, conserved herbage and concentrates on a per ewe and lamb unit basis and per kilogram of carcass produced (Least Square Means \pm SEM)

Parameter	PP			SR			P-value		
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
UFL consumed per ewe and lamb unit⁴									
Grazed herbage	676	669	5.5	672 ^a	643 ^b	703 ^c	6.7	NS	***
Conserved herbage	95	97	0.5	73 ^a	102 ^b	114 ^c	0.61	*	***
Total herbage	771	766	6.0	744 ^a	745 ^a	817 ^b	7.3	NS	***
Concentrates	30	33	0.3	29.3 ^a	30.4 ^b	35.4 ^c	0.3	***	***
Total UFL	802	799	6.2	774^a	775^a	852^b	7.5	NS	***
UFL consumed per kilogram of carcass									
Grazed herbage	23.4	20.2	0.23	21.0 ^a	21.1 ^a	23.4 ^b	0.28	***	***
Conserved herbage	3.3	3.0	0.04	2.3 ^a	3.3 ^b	3.8 ^c	0.10	***	***
Total herbage	26.7	23.2	0.27	23.2 ^a	24.4 ^b	27.2 ^c	0.34	***	***
Concentrates	0.99	1.06	0.007	0.91 ^a	0.99 ^b	1.17 ^c	0.009	***	***
Total UFL	27.8	24.1	0.28	24.1^a	25.4^b	28.4^c	0.34	***	***

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential,

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

^{a,b,c} Within rows, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05),

Table 6.5 The effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on the kilogram of lamb carcass produced per ha (Least Square Means \pm SEM)

	PP			SR				P-value	
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
Lamb carcass output (kg per ha)									
Grazed herbage only ³	293	334	11.3	291	314	335	13.8	*	NS
Grazed herbage plus supplementation ⁴	52.7	62.4	5.4	30.4 ^a	53.7 ^{ab}	89.0 ^b	6.6	NS	*
Total lamb carcass produced	346	396	8.5	321 ^a	368 ^b	424 ^c	10.4	*	***
Proportion of lamb carcass produced off grazed herbage ⁵	0.85	0.85	0.023	0.91 ^a	0.85 ^{ab}	0.79 ^b	0.028	NS	*

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential,

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

³Lamb carcass produced off grazed herbage without any supplementation,

⁴Lamb carcass produced from grazed herbage and supplementation (including concentrates at grass and housed and fed conserved herbage and concentrates),

⁵Proportion of lamb carcass produced from grazed herbage without supplementation of total lamb carcass production,

^{a,b,c} Within rows, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05).

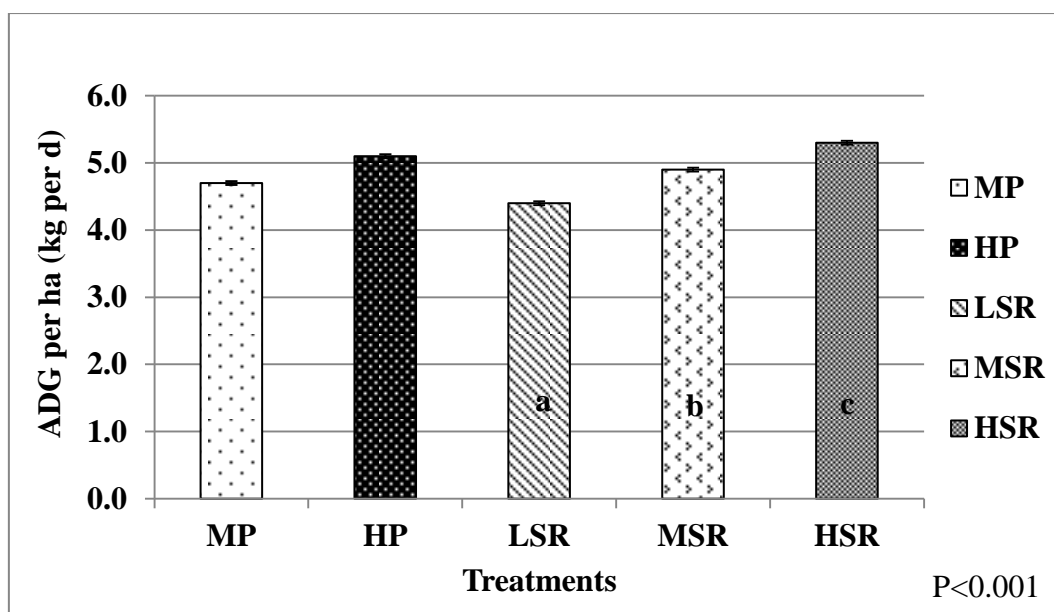


Figure 6.1 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on daily lamb live weight gain per ha from birth to 14 weeks of age

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

^{a,b,c} Within bars, means with differing superscripts significantly differ,

*P<0.05, **P<0.01, ***P<0.001, NS = Not significant (P>0.05),

Error bars represent mean standard error,

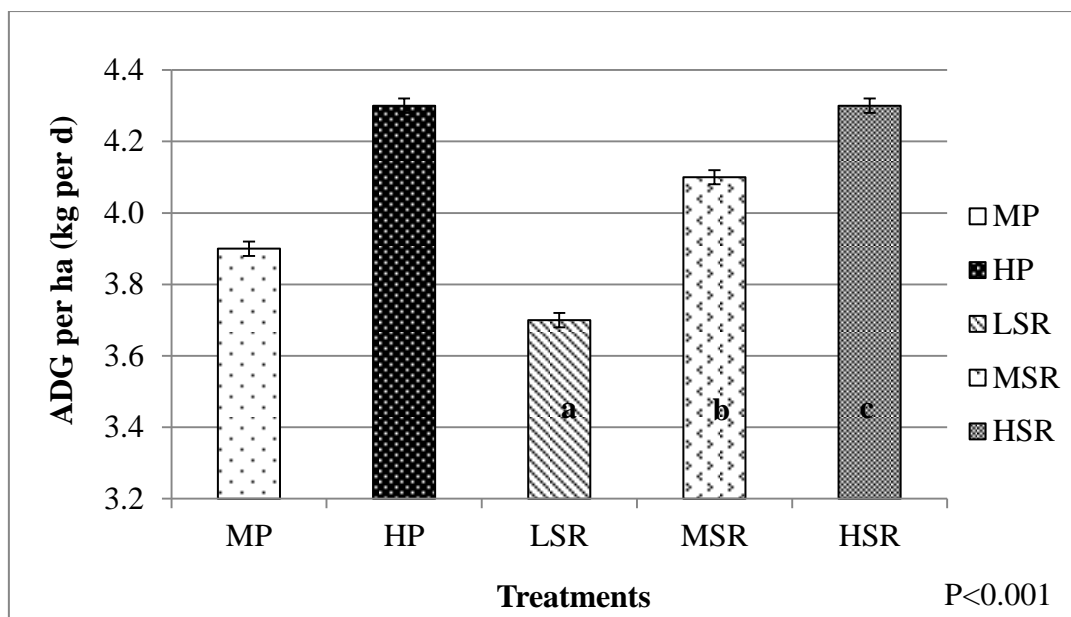


Figure 6.2 Effect of ewe prolificacy potential (PP)¹ and stocking rate (SR)² on lifetime daily lamb live weight gain per hectare

¹Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

²Stocking rate: LSR = 10 ewes per ha, MSR = 12 ewes per ha, HSR = 14 ewes per ha,

a,b,c Within bars, means with differing superscripts significantly differ,

*P < 0.05, **P < 0.01, ***P < 0.001, NS = Not significant (P > 0.05),

Error bars represent mean standard error,

7. Chapter seven

Summary, Discussion and Future Work

7.1 Summary

The development of sustainable livestock production systems is of paramount importance to the supply of nutrients to the world's growing population, especially in light of the decrease in finite global resources such as land and water (Boland et al., 2013; Erb et al., 2012). This combined with the forecasted increase in the global sheep population and consumption of sheep meat in the coming years (OECD, 2016; Thornton, 2010) has necessitated the need to enhance the efficiency of lamb production systems. Ewe prolificacy potential (PP; predicted number of lambs born per ewe per year; Davis et al., 2006) and stocking rate (SR; ewes per ha; Allen et al., 2011) are two of the most influential factors affecting lamb output (Dawson and Carson, 2002; Keady et al., 2009) in pasture based production systems. The work reported in this thesis aimed to evaluate and establish an understanding of the effects of ewe PP, SR and their interaction on the efficiency of lamb production and grass utilisation in pasture based systems. This will facilitate farmers in achieving optimal animal and pasture performance and enhance the efficiency of lamb production. The main findings are summarised below:

Chapter 3

Effect of ewe prolificacy potential and stocking rate on primiparous flock performance.

The objective of this chapter was to evaluate the effect of ewe PP, SR, and their interaction on primiparous ewe and progeny performance in a temperate grass-based lamb production system. The main findings are as follows:

- There was no interaction observed between ewe PP and SR on primiparous ewe performance.
- Medium PP ewes had a consistently heavier body weight (BW) and had a higher body condition score (BCS) at initial mating, pregnancy scanning, 6 weeks post-lambing and weaning.
- At second mating (at the end of the first production year), LSR ewes had a higher BW compared to MSR and HSR ewes.
- Lambs born to HP ewes had a lower average daily gain (ADG) up to 6 weeks of age.

- There was a PP by SR interaction observed for lamb ADG from 10 to 14 weeks of age with HP lambs achieving a lower ADG at the HSR but a higher ADG at the LSR and MSR
- Ewe PP had no effect on pre- and post-weaning or lifetime lamb ADG, days to slaughter or carcass traits.
- Medium SR and HSR lambs had a lower pre-weaning and lifetime ADG compared to lambs at the LSR and subsequently required longer to reach slaughter but no differences in lamb carcass traits were observed.

Deductions from this study are that ewe PP has no effect on lamb performance after six weeks of age in a primiparous flock. Animal performance is reduced when SR increases from 10 ewes per hectare to 12 ewes per hectare but no further decrease in animal performance occurs when SR increases from 12 to 14 ewes per hectare.

Chapter 4

Effect of ewe prolificacy potential and stocking rate on ewe and lamb performance in a grass-based lamb production system.

This study aimed to investigate the effect of ewe PP, SR and their interaction on animal performance in a multiparous flock in a temperate grass-based lamb production system. The main findings are as follows:

- Medium prolificacy ewes had a consistently heavier BW compared to HP ewes but HP ewes had a higher BCS at lambing and 6 weeks post-lambing.
- Ewes at the LSR had a higher BW and BCS at mating, 6 weeks post-lambing and weaning compared to ewes at the MSR and HSR.
- Lambing difficulty, ewe mother ability and lamb viability did not differ by ewe PP or SR.
- High PP ewes produced a higher average born and weaned litter size per ewe.
- Lambs born to MP ewes were heavier at birth and weaning and had higher pre-weaning ADG.

- Prolificacy potential had no effect on lifetime ADG or days to slaughter with HP lambs yielding a higher carcass weight.
- Low SR and MSR lambs achieved a higher ADG from birth to weaning and weaning weight relative to HSR lambs and did not differ from each other. Post-weaning and lifetime lamb ADG was highest at the LSR, intermediate at the MSR and lowest at the HSR.
- There was a PP by SR interaction for the number of days required to reach slaughter, where MP lambs at the LSR reached their target slaughter weight earlier compared to HP lambs, while at the MSR and HSR, MP and HP lambs did not differ from each other.

Deductions from this study are that there is no interaction between ewe PP and SR on many key performance measures. Increasing ewe PP provides the opportunity to increase lamb output per ewe, and enhance flock performance. Based on this analysis ewe PP and SR had no bearing on lambing difficulty, ewe mother ability or lamb viability, which is a positive finding and demonstrates the potential to increase ewe PP and SR without negatively impacting these parameters. In addition, the lack of effect of ewe PP on lifetime lamb performance, increased kill-out proportion and carcass weight demonstrates further the potential to increase the efficiency of lamb production through the use of prolific ewe genotypes. Results from this chapter demonstrate that there are some limitations to increasing SR above 12 ewes per hectare in a grass-based lamb production system due to reductions in individual lifetime lamb performance.

Chapter 5

Evaluation of the effects of ewe prolificacy potential and stocking rate on herbage production, utilisation, quality, and sward morphology in a temperate grazing system

The objective of this study was to investigate the effects of ewe PP, SR, and their interaction on herbage dry matter (DM) production, utilisation, and quality and sward morphology in a temperate grass-based lamb production system. The main findings are as follows:

- There was no interaction observed between ewe PP and SR on herbage DM production, utilisation, quality, or sward morphology.
- Ewe PP had no influence on herbage DM production, utilisation, quality, or sward morphology.
- Herbage DM production and utilisation was highest at the HSR, intermediate at the MSR and lowest at the LSR.
- The MSR and HSR treatments had a higher proportion of leaf in the sward above target post-grazing sward height compared to LSR.
- Grazing season length was lower at the MSR and HSR compared to the LSR.

Deductions from this analysis are that there is potential for sheep producers in temperate grazing regions to increase the ewe PP of their flock in conjunction with higher SR without negatively affecting sward productivity. Increasing SR and grazing severity increases herbage DM production, utilisation and the proportion of leaf material within the grazing sward. Producers can increase flock productivity through increasing the ewe PP of a flock without needing to increase herbage DM production or utilisation.

Chapter 6 Measures of lamb production efficiency in a temperate grass-based system differing in ewe prolificacy potential and stocking rate

The objectives of this study were to quantify the effect of ewe PP and SR on

- 1) ewe production efficiency (kg lamb live weight weaned: kg ewe live weight mated), lamb output per hectare, and lamb carcass output, and
- 2) to quantify the quantity of dry matter (DM; kg) and energy (UFL; Unite fourrage laite per kg DM) required to support the ewe and lamb unit and to produce a kilogram of lamb carcass in a temperate grass-based lamb production system.

The main findings are as follows:

- The HP treatment weaned more lambs on a per ewe and per hectare basis, with HP progeny yielding a higher ADG per hectare and a higher lamb carcass output per hectare.

- High PP ewes had a higher production efficiency.
- Ewe PP had no effect on the total quantity of DM and UFL consumed per ewe and lamb unit. Less DM and UFL was required to produce a kilogram of lamb carcass in the HP treatment compared to the MP treatment.
- Increasing SR increased the number of lambs weaned per hectare and increased lifetime lamb ADG per hectare.
- Lamb carcass output per hectare was highest at the HSR, intermediate at the MSR, and lowest at the LSR.
- The HSR treatment consumed a higher quantity of DM and UFL per ewe and lamb unit compared to the LSR and MSR treatments, with the quantity of DM and UFL per kilogram of lamb carcass produced increasing as SR increased.

Deductions from this chapter are that HP ewes are more efficient in the production of lamb. Increasing SR provides the opportunity to increase lamb carcass output per hectare, however achieving this increase in output required additional DM and UFL per ewe and lamb unit above 12 ewes per hectare.

7.2 Discussion

The use of prolific ewe genotypes and higher SR provides the opportunity to increase lamb output (Keady et al., 2009), however, conversely both higher ewe PP and SR levels are often associated with reductions in individual animal performance (Macdonald et al., 2008; Morris and Kenyon, 2004). Grass, either grazed or conserved, has the potential to supply up to 95% of the energy requirements of sheep (Davies and Penning, 1996), with imposed grazing management decisions significantly influencing sward productivity and quality (Francis and Smetham, 1985; Webby and Sheath, 2000). Following a review of the literature it was clear that there was a limited amount of information available comparing the effects of ewe PP, SR, and their interaction on animal and pasture performance in temperate grass-based lamb production systems, all of which play a fundamental and integrated role in determining the efficiency of lamb production in temperate grazing systems.

The use of available genetics as well as improvements in flock nutrition and grazing management (Keady et al., 2009; Rattray, 1981) provides producers with the opportunity to

not only increase lamb output but also increase the efficiency of lamb production in grass-based systems. Increases in flock prolificacy level have been shown to increase lamb production but this often results in lower progeny birth weights (Keady et al., 2009), growth rates (Thomson et al., 2004), and weaning weights (Snowder and Glimp, 1991). It is evident from the greater number of lambs born and weaned per ewe and per hectare in Chapters 4 and 6 and the lack of difference in lifetime lamb performance in Chapters 3 and 4, that there is great potential to increase lamb output. This can be achieved through the use of prolific ewe genotypes, without negatively impacting on lamb performance despite the lower lamb birth weights recorded in Chapter 4.

In addition, the lack of effect of ewe PP on the herbage production, utilisation, and quality in Chapter 5 shows the potential to increase ewe PP without negatively impacting on sward productivity. This combined with the increase in lamb carcass output per hectare and lower quantities of DM and UFL consumed per kilogram of lamb carcass produced in Chapter 6 demonstrates ewe PP to be a pivotal determinant of the efficiency of lamb production in grass-based systems. This increase in efficiency can be primarily attributed to the superior genetic prolificacy potential of the HP ewes for greater litter size (Hanrahan, 1994) and higher individual lamb carcass weights of HP progeny, which was achieved utilising equal quantities of DM and UFL on a per hectare and ewe and lamb unit basis. That is most likely a result of the lower mature body size and subsequent lower maintenance requirements of the HP ewes in the present study (AFRC, 1993; Kenyon et al., 2009).

Increases in SR are commonly associated with increased output per hectare in livestock grazing systems (Macdonald et al., 2008; McCarthy et al., 2012), although this is frequently achieved at the expense of individual animal performance (Stakelum and Dillon, 2007). The effect of SR on animal performance in Chapters 3 and 4 show ewe BW and BCS to be reduced when SR increases above 10 ewes per hectare but SR to have no effect on the number of lambs born or weaned per ewe, with the total live weight of lamb weaned per hectare increasing as SR increased. Lamb performance as shown in Chapter 4 did not differ between the LSR and MSR indicating the potential to increase SR up to 12 ewes per hectare without negatively affecting lamb performance. The ewe PP by SR interaction observed in this chapter for days to slaughter, where MP lambs at the LSR reached slaughter at an earlier age compared to HP lambs, can be attributed to their higher pre-weaning performance relative to HP lambs and also to the increased opportunity of diet selection afforded to lambs at the LSR.

Increased SR is generally associated with an increase in herbage production and utilisation (Macdonald et al., 2008; McCarthy et al., 2012). The results of the analysis carried out in Chapter 5 are in agreement with this and show herbage production and utilisation to increase as SR increased, which in turn increased the proportion of leaf in the grazing sward in the MSR and HSR treatments. Previous research recommended a target PGSH of 3.5 cm for the first grazing rotation and 4.5 cm during the main grazing season in a temperate grass-based dairy system in order to achieve optimum levels of herbage DM production (Ganche et al., 2013) albeit for grazing dairy cows. However, based on results in this chapter the neutral effect of ewe PP and positive effects of higher SR on sward morphology in Chapter 5, it is clear that there is potential to graze below 4.5 cm during the main grazing season within a temperate grass-based lamb production system. The greater quantity of surplus conserved herbage yielded at the LSR was a combined result of the shorter winter housing period required by LSR treatment and the excess of 17 kg N applied per hectare per year which was calculated based on differences between herbage DM produced above the target PGSH and the quantities of herbage utilised. These results demonstrate the potential to adequately produce sufficient quantities of herbage at the LSR and MSR to meet animal grazing and winter feed requirements of animals at a lower N application rate.

Based on the analysis from Chapter 6 on the quantity of DM and UFL consumed per ewe and lamb unit, it is evident that the LSR and MSR systems are equally efficient in the production of lamb and utilisation of feed resources and would indicate a decline in the efficiency of lamb production at a SR of 14 ewes per hectare. When the lack of difference in DM and UFL consumption per ewe and lamb unit between the LSR and MSR treatments is compared with the increase in lamb carcass output per hectare at the MSR, it is clear that increases in output and efficiency are achievable up to 12 ewes per hectare. The decline in efficiency of lamb production at 14 ewes per hectare can be primarily attributed to the lower lifetime lamb ADG and increased days to slaughter observed in Chapter 4 and this must be considered when increasing SR in grass-based systems. The greater number of days required to reach slaughter will result in a greater number of lambs grazing pasture in the autumn period when herbage growth and quality is decreasing as demonstrated in Chapter 5 at in competition with ewes in the pre-mating period.

The work from this thesis demonstrates that there is a lack of interaction between ewe PP and SR in temperate grass-based lamb production systems and that there is potential to increase ewe PP along with SR in a temperate grass-based lamb production system, without affecting pasture and animal performance. Increasing the ewe PP of a flock will increase lamb output and the efficiency of lamb production, although there may be some potential limitations to increasing SR above 12 ewes per hectare in grass-based systems due to lower individual lifetime lamb ADG. Producers should therefore match the SR of their systems to the grass growing potential of their farm.

7.3 Future Work

Future grassland systems research should aim to further increase the efficiency of lamb production through increasing the quantity of grass produced and utilised at farm level. Further work is required to develop grazing systems that increase post-weaning lamb performance in order to benefit fully from the advantages of increasing ewe PP and SR within lamb production systems. This may be achieved through the inclusion of legume species into grazing sward which will increase sward nutritive value during the post-weaning period and enhance lamb performance.

Future research into the long term effects of increasing ewe PP and SR on the parasite burden in grazing sheep systems is also warranted, with particular attention to the periparturient period when young lambs are most likely to be infected by nematode species via transmission from the dam and by the contamination of pasture from the deposition of nematode eggs from the previous grazing season. In addition the reproductive performance and progeny growth are influenced by the nutrition offered, particularly during the grazing season and research into trace element levels in grazing systems managed under different grazing regimes is also warranted.

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8. Chapter Eight

Thesis Publications

8.1 Scientific Publications

- Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2016. Effect of ewe prolificacy potential and stocking rate on primiparous flock performance. *Small Ruminant Research*. 143: 53–60. [Impact factor = 1.083]
- Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2017. Effect of ewe prolificacy potential and stocking rate on ewe and lamb performance in a grass-based lamb production system. *Journal of Animal Science*. 95:1–11. [Impact factor = 2.45]
- Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2017. Evaluation of the effects of ewe prolificacy potential and stocking rate on herbage production, utilisation, quality, and sward morphology in a temperate grazing system. [Submitted (insert date) revised (insert date): *Grass and Forage Science*; Impact factor = 1.62]
- Earle, E., Boland, T. M., McHugh, N. and Creighton, P. 2017. The efficiency of lamb production and dry matter and energy requirements of grass-based lamb production systems differing in ewe prolificacy potential and stocking rate. [Submitted and under review: *Journal of Animal Science*; Impact factor = 2.45]
- Bohan, A., Shalloo, L., Creighton, P., Earle, E., Boland, T. M. and McHugh, N. 2017. Comparing the profitability of an Irish grass based sheep production system under three stocking rates and two prolificacy potentials [Submitted and under review: *Livestock Science*; Impact factor = 1.059]

8.2. Conference Proceedings

8.2.1 Senior author

Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2014. An investigation into the effect of stocking rate and prolificacy potential based on ewe breed type on ewe body weight, body condition score, culling rate and lamb mortality. In: Agricultural Research Forum 2014, Tullamore Court Hotel, Tullamore, Ireland, 10th March 2014. p73.

Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2015. The effect of stocking rate and prolificacy potential on carcass output and lamb performance from pasture based production systems. In: Agricultural Research Forum 2015, Tullamore Court Hotel, Tullamore, Ireland, 9th March 2015. p66.

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Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2016. Effect of stocking rate and prolificacy potential on lamb performance and carcass output from a grass based production system. In: BSAS annual conference 2016. University of Chester, UK, 7th April 2016. p76.

Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2016. Effect of stocking rate & ewe prolificacy on lamb growth, production efficiency and carcass output. EAAP, 67th Annual Meeting of the European Federation of Animal Science, Belfast, UK, 29th August – 2nd September 2016. p499.

Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2016. Effect of prolificacy potential & stocking rate on ewe body weight & body condition score. EAAP, 67th Annual

Meeting of the European Federation of Animal Science, Belfast, UK, 29th August – 2nd September 2016. p502.

Earle, E., McHugh, N., Boland, T. M. and Creighton, P. 2016. Effect of ewe prolificacy potential and stocking rate on grass utilisation and lamb carcass output. EGF 2016, Trondheim, Norway, 4th – 8th September 2016. p 412–414.

8.2.2 Co-author

Bohan, A., Shalloo, L., Creighton, P., Earle, E., Boland, T.M. and McHugh, N. 2016. The effect of stocking rate and prolificacy on profitability of an Irish lowland sheep enterprise. EAAP, 67th Annual Meeting of the European Federation of Animal Science, Belfast, UK, 29th August – 2nd September 2016,. p385.

Bohan, A., Shalloo, L., Creighton, P., Earle, E., Boland, T.M. and McHugh, N. 2016. The effect of stocking rate and prolificacy on profitability of an Irish lowland sheep enterprise. National Sheep Conference, Killarney, Co Kerry, 2nd February 2016, p12–18.

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